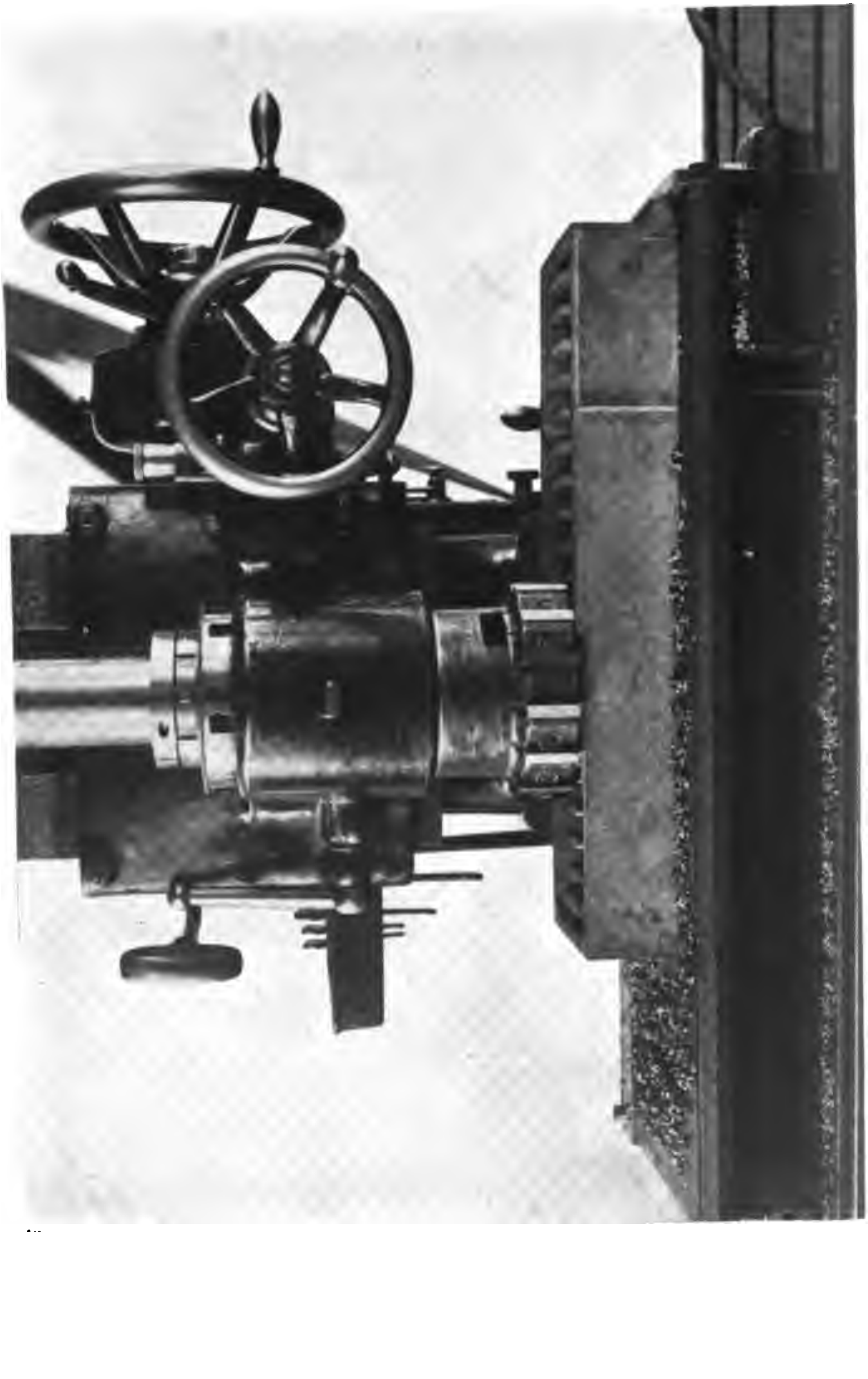

Modern Shop Practice

A General Reference Work on

MACHINE SHOP PRACTICE AND MANAGEMENT, PRODUCTION MANUFACTURING, METALLURGY, WELDING, TOOL MAKING, TOOL DESIGN, DIE MAKING AND METAL STAMPING, FOUNDRY WORK, FORGING, PATTERN MAKING, MECHANICAL AND MACHINE DRAWING, ETC.

Editor-in-Chief

HOWARD MONROE RAYMOND, B. S.

Dean of Engineering, Armour Institute of Technology

Assisted by a Corps of

MECHANICAL ENGINEERS, DESIGNERS, AND SPECIALISTS IN SHOP METHODS AND MANAGEMENT

Illustrated with over Two Thousand Engravings

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost manufacturers and engineering firms, in making these volumes thoroughly representative of the best and latest practice in machine and pattern shops, foundries, and drafting rooms, and in the construction and operation of machine tools, and other classes of modern machinery; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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HEAVY TOGGLE DRAWING PRESS
Courtesy of Toledo Machine and Tool Company, Toledo, Ohio

Foreword

A LITTLE more than a century ago our mechanical development had its beginning when the first prime movers were invented and developed. With the development of machines came the development of mechanics to run these machines, to fabricate the parts and assemble them into the finished articles. The evolution of both machines and mechanics has been marvelous, the accuracy of workmanship of today being easily two hundred times that of a century ago, and the speed of manufacture probably much more than this. Since that time one industry has helped to develop others until today the mines produce ore in large quantities to supply the iron, copper, and other metals; the great steel mills supply the raw or fabricated material; the foundries and forging shops fashion the many castings and forgings for the intricate machine to be built; the immense shops machine the parts and assemble them for the market. Everywhere we turn we find a manufactured article which has gone through these various changes from raw material to finished product.

¶ "Production" methods have enormously increased the output of our shops and the machines which have made this development possible are of a diversified character—speed lathes, planers, multiple drillers, grinders, milling machines, stamping machines, die presses and the jigs, tools and dies which go with them—all of these have contributed to the accuracy and speed of manufacture. The demands of the automobile industry have done wonders in hastening this development as the manufacture of the parts in duplicate was absolutely necessary in order to cheapen the price of the assembled machines. The fact that many of the present-day automobiles

are shipped "knocked down" to assembly points without ever having been put together is an eloquent testimonial to the accuracy with which the duplicate parts are built. Another contributing factor in modern production methods is the development of high speed steels which enable the operators to run the machines at speeds hitherto unattainable.

¶ And yet with all this wonderful development of the machines themselves and the design of what are termed "automatics," the workman has not lost his skill. In fact, one trip to a well-organized scientific machine shop will teach any skeptic that the intelligent workman who has contributed so largely to the mechanical developments of the past twenty years is more skilled, more intelligent, certainly better paid, and more interested in his work than ever.

¶ But this same skilled mechanic is today a specialist. He has no opportunity to build a complete machine or even a small part of one; his active work is carried on along rather narrow lines. Consequently, it is all the more necessary for him to have a standard reference work to help him in other shop lines with which he is unfamiliar. "Modern Shop Practice" is such a work—one which has been tested through six editions—and the practical treatises on the various shop subjects have been supplied by well-known teachers and practical men and are strictly up-to-date. The authors have at all times kept in mind the practical nature of their subjects and numerous shop kinks and other helpful suggestions have been introduced. It is the hope of the publishers that this new edition will supply the needs of both the skilled mechanic and the layman who is interested in mechanical affairs.

¶ In conclusion, grateful acknowledgment is given to the authors and collaborators — engineers and designers of wide practical experience and teachers of recognized ability—without whose co-operation this work would have been impossible.

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ROTARY SURFACE GRINDER GRINDING HIGH-CARBON STEEL GEARS
Courtesy of Heald Machine Company, Worcester, Massachusetts

MACHINE SHOP MANAGEMENT

MANUFACTURING

Manufacturing Conditions and Developments. Millions of dollars are annually spent in building new factories. Other millions are spent in equipping them with the best machinery that trained and experienced men have been able to devise. Still more millions of money are annually paid to the officials who manage and the employees who man these enormous manufacturing plants.

Why? Why could not these expert employees labor in their own homes or their individual shops, and produce the manufactured goods without all these enormous expenses? What are the necessities which impel men to spend these vast sums of money in erecting, equipping, and operating these immense plants?

Casually considering the question, the *factory* or *manufacturing plant* does not seem to be a real necessity. A large force of employees working under a single management does not seem to be the most economical method of producing the desired goods. Certainly every man is free to choose his own particular line of work; and there are many persons who, seeing a large force of employees giving their entire life work to the enrichment of successful manufacturers, while the employees themselves work long hours at hard and laborious tasks and fare so poorly that they are seldom enabled to save any considerable portion of their wages, not infrequently ending an industrious life in poverty and want, are led to believe that the factory is not a necessity or even a benefit to mankind, but rather a means for reducing the individual worker to a condition of grinding servitude, voluntary perhaps, but often the result of dire necessity.

These people, considering all the hardships in the life of factory employees, are likely to hold and often to express the opinion that the highest welfare of the human race really demands a return to the simpler life of early days, when a much larger proportion of the people lived upon farms, producing their own provisions, raising the flax

and the wool wherewith they clothed themselves, quite independently of the wealthy classes, whether bankers, capitalists, or manufacturers, the factory as we know it to-day having hardly begun its marvelous era of existence.

Let us consider for a moment how all this has come about. In the earlier years of the independence of this country, the chief dependence was upon the results of agricultural work. In due time the development of the resources of the country has placed manufacturers at the front, so that in very recent years the value of manufactured products has become nearly double that of agricultural.

These results, like many others of a less notable character, commenced from very small beginnings; and it has been by inborn mechanical ability, remarkable ingenuity, patient development, and tireless energy, that mechanical undertakings have been developed from meager initial facilities, until, in the vast manufacturing enterprises of the present day, the American mechanic in nearly all lines leads the world in originality and practical achievement.

Early New England Mechanics. When the early settlers of New England labored under the restrictive and harassing laws of the Mother Country, and under their administration were goaded and exasperated beyond endurance in many ways, not the least of which was that of being obliged to purchase many manufactured articles from England at extortionate prices—or, if purchased from other countries, still paying taxes to England for the privilege—they rebelled. Determining to buy no more foreign goods, they set out, at first in a most clumsy and primitive fashion, to make for themselves such articles as were really necessaries, and, in noble self-denial, to live without those which they could not make for themselves. They doubtless little realized, however, that they were thereby laying the foundations of the greatest manufacturing country in the world. By the principles thus inaugurated, they instituted the first industrial *boycott* in the history of the country—the one that has had more important and far-reaching influences than anything of the kind before or since.

Industrial Freedom. While the departure of the Pilgrims for this country, and the making of their homes on the "stern and rock-bound coast" of New England, were for the purpose of seeking religious freedom, it is also true that freedom soon meant very much more than

this to them; and with a larger conception of their opportunities and possibilities, some of which were in reality forced upon them by adverse circumstances, there came to them the inspiration of *industrial* as well as *religious freedom*. The world has seen and has given them due credit for the determined and heroic manner in which they went about their self-appointed task; and they have amply demonstrated to posterity their appreciation of and grasp upon the possibilities and conditions, and the breadth and nobility of character which they exhibited in working out the many perplexing problems that confronted them.

Development of American Industrial Enterprises. American manufacturing came into being with these small beginnings and crude efforts to fashion those common objects of household necessity and daily use, which, although crude and clumsy, yet answered the purpose until supplanted later by those of more improved form and workmanship. These primitive successes led to greater endeavors, and developed into still broader usefulness, when the time came that necessities had been provided for and luxuries were now demanded by the higher plane of living to which the people had in due time advanced.

Thus the crude beginnings and rude surroundings among which the early American mechanic performed his work, were in his own house. Soon he outgrew these primitive facilities, and built small shops, frequently in the garden or back yard of his home. These gradually enlarged. The development of the business demanded increased facilities, and buildings were erected quite independent of the home surroundings, and two or more men were associated as manufacturers. These plants developed and enlarged, and in due course of time became the machine shops and the factories, which have since multiplied many hundreds of times, not only in number and in value, but in influence and importance, until to-day our country stands the foremost manufacturing nation of the world. This is true, not only as to the volume and value of her manufactured productions, but also as to their great range and diversity of kind and usefulness. One by one the American mechanic has taken up the various classes of work formerly monopolized by this country or that, failing perhaps at first, but always progressing and developing, until, by native ingenuity and unflagging energy, all obstacles have been overcome,

all difficulties put aside, new industries have come into being, and other "victories" of peace "no less than those of war" have been added to the laurels of the American mechanic and of his ever-ready and ever-confident partner, the American manufacturer and capitalist. It is to this combination, each confident of and faithful to the abilities and honor of the other, and each acting his part in his own sphere of usefulness, that the immense success of American manufacturing is due.

The factories of to-day are the logical results of a natural growth and development of the various branches of business for which they were originally built and organized. As the buildings increased in numbers and dimensions, the methods of construction, the equipment, and the systems by which they were managed, developed methods of greater economy and efficiency.

Tools of the Early Mechanic. The early mechanic had few tools and appliances wherewith to perform his work; and these were crude and primitive, consisting principally of a limited number of hand-tools brought from the Old Country, and occasionally a hand-lathe of modern dimensions and operated by foot-power. But with their few tools and meager facilities, and animated by the condition that "necessity is the mother of invention," these old-time mechanics proceeded with practical common sense and ingenuity to design and construct better tools and machines—which have continually developed, until we have the splendid array of manufacturing machinery seen on every hand to-day. As machinery developed, larger and larger amounts of money had to be expended; and the banker had to be called upon to provide it. Thus the capitalist became the partner of the manufacturer, the one furnishing the mechanical ability and inventive genius for the actual designing and building of machinery and manufactured goods, while the other contributed the money to carry on the work, and the business ability necessary to market the product.

Relations of Capital and Labor. In brief, this is the condition to-day. But, says the carping critic, "there are often hundreds of struggling and hard-working employees where there is one rich manufacturer." This may be partly true, although it is a fact beyond dispute that the American mechanic is the best paid workman in the world. It is true that there are hundreds of workmen to one capital-

ist. Why? The Creator has so ordained that there shall be many of moderate ability, and but few possessing the unusual ability and talent to lead them. So it has ever been since the days of Moses, and so it probably will ever continue to be. Doestick's regiment composed entirely of colonels was a manifest absurdity, and so intended as an illustration of a well-known and natural condition that should be realized by every reasonable and thoughtful man who considers these questions.

Considering carefully the great scheme of manufacturing, and the immense industrial problem of supplying the wants of the people of this great country and providing for the vast volume of trade that goes abroad, by the modern manufacturing plants equipped with all that is latest and best in machinery for every conceivable purpose, it should not be forgotten that, as the very basis and foundation of the whole, stands the modern *machine tool,* and that it is principally to the great and important development of this that we owe primarily our industrial growth and prosperity as a manufacturing nation To the machine tool may easily be traced the gradual but continued upward tendency of the mechanic and his methods, from the hard physical toil and small pay of the early days, to the immeasurably lighter exertion and increased compensation made possible by the highly developed condition of the automatic machines of the present day. It has been an oft-repeated victory of "mind over matter," wherein *brains* have won where *hands* made but little advance; *ideas* have developed wonderful mechanisms that have revolutionized the earlier methods of manufacturing and raised the standard of mechanical excellence beyond what was thought possible years ago, and at the same time reduced the cost to a fraction of its former amount.

Here, again, the capitalist furnished the means whereby the practical realization of the ingenious designs of the mechanic's fertile brain became possible, and the successful combination of capital and labor brought success to both.

Combinations of Capital. But here comes our critical labor agitator again with the comment: "It is all very well to talk about the amicable relations of capital and labor, and how each ought to help the other, but how about the great combinations of capital that we ordinarily call "trusts"? To give a correct and intelligent, as well as a fair and truthful answer to this question, we must know the

conditions under which the combination is formed, the *plan* upon which it is organized, and the *object* of its formation. As these are not given, we must assume the conditions of some well-known combination. Let it be the United States Steel Corporation. One of the foremost men in this combination has defined his position on the subject, and in so doing has outlined the policy of the corporation, by saying:

"Any combination of capital which operates, *first*, to prevent competition; *second*, to increase the price of the product; and *third*, to reduce the wages of the workmen, is working under a trio of wrong principles that sooner or later will bring about disaster."

Let us see how the actual operation of this combination of capital really works out in practice.

First—The Steel Corporation has never sought to prevent competition. Steel mills, large and small, have operated when, where, and how they pleased, with no interference from the Steel Corporation.

Second—The price of steel has not been increased; on the contrary, it has been greatly reduced under its management. Thirty years ago a very indifferent quality of machine steel cost from 8 to 12 cents per pound. To-day ordinary machine steel of a much better quality than that mentioned above can be had for 2 cents a pound or less.

Third—The wages of workmen have not only not been reduced, but have actually been doubled since the labor troubles in the steel mills known as the "Homestead Strike" (1892). The Steel Corporation has gone much further than to double the wages of the steel workers. They have made it possible for the workmen to become partners in the great work of the corporation, by obligating themselves to sell to their workmen a certain amount each year of stock in the corporation, so that the men who labor in the mills may also become part owners and participate in the dividends resulting from their work on exactly the same percentage as the capitalist himself does.

Our critic comes back to the charge by saying that "the Steel Corporation has bought up many steel plants in various parts of the country, and added them to its already enormous properties." Quite true. And for what purpose? Let us see what they do with these plants. How do they manage this part of the business? What is their plan of working? The conditions were these: Before the advent of the United States Steel Corporation, there were many isolated steel manufacturing plants, each being equipped for the making of a number of kinds of steel products—for instance, steel railroad rails, structural steel, merchant bar steel, steel boiler-plates, steel tank-plates, and so on. The equipment necessary for producing these different forms of steel was very expensive; and inasmuch as a considerable portion of this equipment for some particular kind of product would necessarily be idle on account of the fluctuations of trade, the expense burden was abnormally high on account of this idle equipment. How has this condition been handled by the Steel Corporation? This has been the plan: Suppose they have purchased five plants, each making the five classes of product indicated above, and working

under the disadvantages of a variety of products. These plants are examined, and inventories made of their equipments. It is then decided which mill is best adapted for making each one of the five classes of products. Then there is a redistribution of the equipment of the plants, placing in the plant selected for it all that in the several plants is adapted to a certain product; removing all the machinery from this plant that is not adapted to the particular product to be turned out, to be distributed among the other plants according to the particular class of products for which each one is designed. Thus each plant is equipped to turn out the single class of product which is most appropriate for it, by drawing upon the other plants for such machinery as they have which may supplement its own in this line.

By this plan, each plant makes but one class of product. Having the best machinery from all the plants for this purpose, and concentrating its energies on a single class, it is enabled not only to turn out a better product, but to turn it out much more economically than before. As the workmen become more expert on their single line of product, they work more efficiently and consequently earn higher wages. All these conditions, producing an economical output, enable the manufacturers to reduce the selling price.

The conditions of economy brought about in the management of the manufacturing operations and in marketing the product, are very marked when a large number of plants operate under one general head. Again, with the immense amount of capital at the disposal of such a corporation, it is enabled to secure the services of the best experts, and the most valuable processes in existence.

There are many other advantages, not only to the corporation and its employees, but to the users of its products, and so to the general public, when a combination of capital is *honestly made and honestly administered.*

Betterment of Industrial Conditions. What has been said of the Steel Corporation as to favoring of employees, has been duplicated in various ways by different manufacturers all over the country. Factory sites have been beautified by landscape gardening, and trees and shrubbery have made the surroundings of working men and women pleasant and attractive. Land has been purchased, and workingmen's homes built and rented to them at fair rates. Factory dining rooms are provided; reading rooms, libraries, gymnasiums, clubs, and social organizations are inaugurated; emergency hospitals or "first aid" rooms are arranged, with all or nearly all these services free except that provided in dining rooms, which is furnished at actual cost. More recently, a firm in Connecticut announces that it will furnish free medical attendance to all its employees and their families.

Schools have been established for apprentices, wherein they receive such technical instruction as may be necessary to their success in the trade they are learning—and this, not only without expense to

themselves or to their parents, but they are paid by the hour for time spent in their school work, the same as for their time in the shop.

To foster a practical interest in the work of the shops, many concerns have what is called the *Suggestion System,* whereby the employees may make written suggestions of any improvements which they desire as to shop methods and routine, the design and construction of the product, and many kindred subjects, the best suggestions made each month receiving prizes.

All of these matters emphasize the fact that the mutual interests of the capitalist who manufactures and sells, and of the employee by the efforts of whose hand and brain the products are being turned out, are each year being recognized and in a very large majority of cases are being acted upon in good faith.

Methods of Modern Manufacturing. In former times, machines were built one at a time or in very small lots. Parts were made and fitted to the particular machine to which they belonged; and while the same general form and dimensions were practically maintained, there was no attempt made to render the several parts so exact as to fit upon any other machine than the one for which they were intended. Systems of gauges had not been developed, and the planer was yet a comparatively new tool; much work was still done by hand, the hammer, the cold chisel, and the file being the chief reliance of a large majority of machinists. This was the state of the machine shop and its methods nearly up to the year 1800.

Interchangeable Manufacturing. The use of milling cutters and the commencement of practically interchangeable manufacturing, came into machine shop practice at nearly the same time. It has been said that "but for the milling machine, there would have been no such thing as interchangeable manufacturing." It might be said with quite as much truth, that if the system of interchangeable manufacturing had not been conceived, there would have been little need for the milling machine. Each, to a great extent, depended very much upon the development of the other—and upon a third factor, the conception and development of the method of handling work (particularly small parts) in jigs and fixtures.

Vaucanson. Milling cutters were made in America by one of the early machinists, a Frenchman named Vaucanson, who died in 1872. A sample of these had a hexagonal instead of a round hole, and the

pitch of the teeth was very fine, so that the cutter was more like a circular saw than the cutters in use at present. It is said that a man by the name of Bodmer, in Manchester, England, had made a milling machine in 1824.

Eli Whitney. It is altogether probable that Eli Whitney, the inventor of the cotton gin, had built and used milling machines previous to this date, as the following item of mechanical history would seem to indicate. In January, 1798, Eli Whitney received from the United States Government an order to furnish ten thousand muskets, of which four thousand were to be delivered in one year, and the balance in two years. Mr. Whitney went at the undertaking in a very thorough and systematic manner. He first developed a water power; then erected suitable buildings; considered and developed ways and means for a larger and better product than had previously been realized; designed and built machinery to effect it; and trained workmen to a degree of skill necessary to success in their new employment.

The difficulties which Mr. Whitney encountered and the obstacles which he had to overcome, were so much greater than he anticipated that it was really eight years instead of two before he had succeeded in completing the government order for the ten thousand muskets. However, the progress which he had made in this new enterprise, and the character of the product which he turned out and delivered, were so satisfactory to the government officials that Congress treated him with the greatest courtesy and consideration.

His shops were situated in the city of New Haven, Conn., and soon became the Mecca of government officials, manufacturers, traveling notables, and foreigners, who had heard of this wonderful American mechanic and came to see his work for themselves—to find that the system, the machines, and the tools which he had perfected were well worth the journey. His innovations in the manufacture of arms formed as great an epoch in mechanical history as had his invention of the cotton gin.

Jigs and fixtures were among his equipment; and it is altogether probable that milling machines were also in use, since he must have had practical knowledge of the utility of the milling cutter at this time, as it is generally assumed that the first practical use of the milling machine was in the making of parts of muskets.

The buildings which Mr. Whitney erected for his use were substantial stone structures, and stand in a part of the city called in his honor "Whitneyville." They form a part of the extensive plant of the Winchester Repeating Arms Company.

Modern Methods. At this point and at this early day, therefore, was inaugurated the modern system of interchangeable manufacturing—or the manufacturing, in large numbers, of duplicate parts, within such a limited degree of variation as to admit of their ready interchangeability with one another. The system was not one that would be confined to the manufacture of arms, but was adaptable to the production of all kinds of small and moderate-sized machinery, and was the initial effort which in due time revolutionized the then existing shop methods, and which has since built up the American system of manufacturing to the proud distinction of being superior to anything of the kind in other manufacturing countries.

In the operations of modern manufacturing, the principal object sought is to turn out the product economically and accurately. To produce these results economically, the parts must be produced very rapidly. To produce them rapidly, not only must there be a very complete and efficient equipment of machines, attachments, tools, jigs, fixtures, and gauges or measuring devices, but there must also be a very complete system of shop methods by which the operation of this equipment is carried on.

It has been well said that "the man in whose brain the manufacturing system was born was he who first took a piece of scrap iron and drilled two holes in it, to guide a drill in making another piece with two holes in it the same distance apart as in the first piece." The men who now fill our drafting rooms and tool rooms, and who devise and construct tools for the production of interchangeable metal parts, are his descendants. They have made possible the manufacture of the breech-loading gun, the typewriter, the cheap sewing machine, the cash register, the machine-made watch, the automobile, as well as a thousand and one other mechanical articles, machines, and devices which form an integral part of our twentieth-century civilization.

To render these systems efficient and economical for these purposes, the work must be *repetition or duplicate work.* That is, there must be very large numbers of each of the different parts; and to carry out the scheme of operation for the division and subdivision of work,

a single operation on a large number of parts is performed; then the work is handled again, perhaps in another machine, and another operation is performed; and so on until the part is complete. Thus a piece of comparatively simple form may require a large number of separate and distinct operations to complete it. But, as each single operation is performed by one operator, he may give his undivided attention to the accuracy of that operation; hence very accurate work can be produced.

Increase in Production. In the development of these systems, the work has continually grown more and more complex, as have also the requirements as to the buildings in which manufacturing work is performed, and as to the equipment necessary to perform it. Conditions have been continually changing; greater speed as well as greater accuracy in all machine operations has been demanded; and a largely increased output per employee has been required. So great and urgent has been this demand that the employee of today will turn out from three to ten times the volume of product of a given kind that he did only a few years ago. Undoubtedly this result has been brought about in large measure by the great improvement in machines, tools, and fixtures; also by the use of tools composed of high-speed steel; and still more to improved systems for handling work.

But all of these do not fully explain the enormous increase in product per employee. This has been brought about by various methods of shop management. One of these is the specialization of operations and the division and subdivision of departments, whereby each operator has a certain well-defined and very limited number of operations to perform. These operations he performs over and over, hundreds and sometimes thousands of times daily, until he becomes so accustomed to each movement that the operations are performed not only with great rapidity but also with great accuracy. Still another factor in the question of individual output, is the efforts that have been made through systems of premiums, bonus, and similar methods of reward for individual effort when the output reaches or exceeds a certain fixed limit. These rewards are not confined to the operatives, but are often extended to the foremen, assistant foremen, gang bosses, and others of the "non-productive" force who have indirectly contributed to the efficiency of individuals and hence to departmental efficiency.

In the succeeding articles, these matters will be taken up and treated in detail, giving the actual practice as now prevailing in some of the best organized manufacturing plants.

MACHINE SHOP MANAGEMENT

Modern Meaning of Shop Management. The present understanding of the term *Shop Management* is quite different from the sense in which it was used years ago. Formerly the management of the shop was vested in a *superintendent* whose duties consisted in purchasing material, inspecting it when it was received, turning it over to the foreman, and in a general way looking after the work as it was being performed. In addition to these duties, he frequently handled the selling of the product, the collection of accounts, and the proper provision for meeting the pay-roll on pay-days. He also had a general supervision over the grounds and buildings and their care and maintenance, as well as the provision for power, lighting, and heating. By this arrangement of duties, it will be seen that comparatively little time was devoted to actual shop operations, and much time to different lines of duties that might more economically and often quite as efficiently be performed by assistants at a much lower rate of pay.

In the modern methods of shop management, all these things are changed. The specialization of workmanship, the division of duties, the limiting of responsibilities—each restricted within narrow limits by sharply defined regulations—have reduced the variety of operations of the workman, and of responsibilities and duties of the men who direct manufacturing work.

We find the purchasing of material and supplies in charge of a *Purchasing Agent.* We find these purchases checked by a *Receiving Clerk,* turned over to a *Storekeeper,* and subject to examination by a regular *Inspector.* They are then put into the store-room, whence they are drawn as needed for the different departments, the foremen of which sign definite orders for such kinds, quantities, and qualities as may be needed, specifying the purposes for which they are to be used or the particular orders to which they are to be charged. When issued, they are receipted for by the person receiving them. All this is conducted with the same regard for business rules as if the foreman were making a purchase on his own account and paying for the goods. We find the selling of the product in the hands of an expert *Sales*

Manager, often assisted by a corps of engineers, draftsmen, bookkeepers, and clerks, numbering more persons than the entire factory's force of non-producers twenty years previously. A *Credit and Collection Department* attends to all collections, and the *Treasurer* and *Cashier* see to it that the money for the pay-roll is on hand when wanted. A *Production Engineer* regulates the volume of work going into the shop, and the sequence of mechanical operations by which each piece or part is to be machined and perfected. An assistant to the Superintendent looks after the condition and maintenance of grounds and buildings, yards, and the transportation facilities of the plant.

By these developments of the system of management into a division of duties and responsibilities, the time, attention, and abilities of the Superintendent may be devoted to his legitimate purposes of *superintendence* or *supervision*, planning and directing the work of the assistants and heads of departments.

A Typical Manufacturing Plant. For the purpose of taking up the question of Management in a systematic and practical manner, we must first assume that we have a shop to manage; and secondly, that it is of the usual type of manufacturing plant built, organized, and managed at the present day. The plan of such a plant is given in Fig. 1.

In planning a plant of this character, provision must primarily be made for the various departments for the following purposes:

1. An *Engineering Department*, wherein the machines forming the product may be designed and the drawings made for the various classes of mechanics who are to perform the work of turning out the product.

2. A *Pattern-Making Department*, in which the necessary patterns are made for use in the foundry for producing the castings.

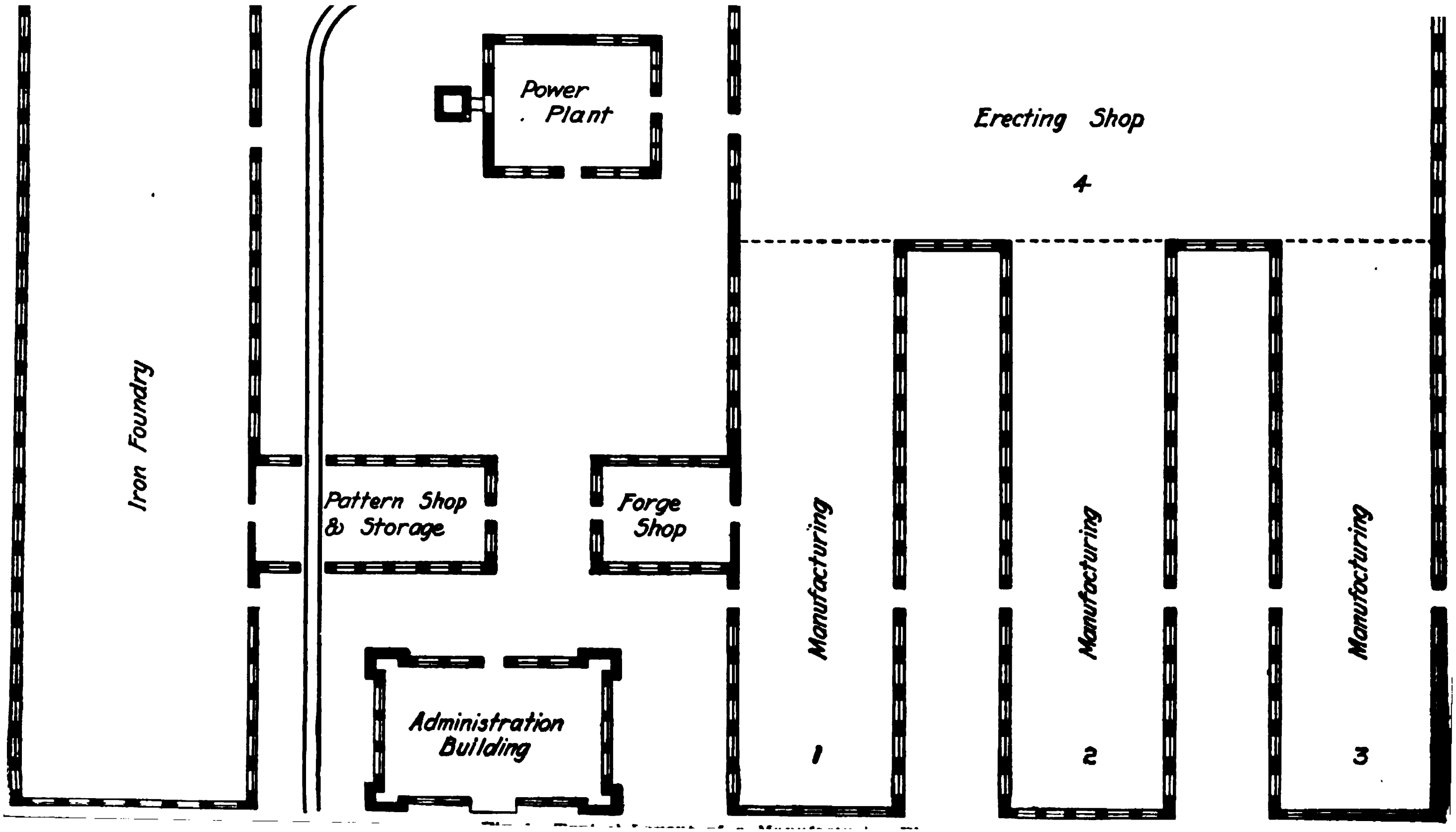
3. A *Forge Shop*, capable of producing such forgings as are required in the machinery to be built.

4. An *Iron and Brass Foundry*, in which may be produced the rough castings of the parts that are to enter into the machines constituting the product.

5. *Manufacturing Departments*, in which all parts (large and small) of the product are made from the rough stock—such as castings, forgings, bar stock, and the like, to the completed parts ready for assembling.

6. *Assembling and Erecting Departments*, in which individual parts may be assembled into groups of related parts, and these erected into complete machines.

7. A *Power Plant*, containing the proper equipment for furnishing the necessary power for driving the machinery in these various departments, and for providing lighting and heating facilities for the plant.


Power
Plant
Erecting Shop
4
Iron Foundry
Pattern Shop
& Storage
Forge
Shop
Manufacturing
1
Manufacturing
2
Manufacturing
3
Administration
Building

The *General Office* of the concern is of course understood; but, as it cannot properly be classed with departments of the plant, it is not included in the above enumeration.

In addition to the above list of principal departments, there will be the following—quite as necessary, but secondary in importance:

1. The *Transportation System*, including shop and yard tracks and cars, elevators, cranes, hoists, and all similar appliances for handling material.
2. The *Tool Room*, for making tools, jigs, and fixtures, and for properly storing them in a convenient manner for issuing when they are called for.
3. An *Experimental Room*, which all progressive concerns find necessary in the development of their product.
4. The *Store-Room*, in which are stored the raw material and the purchased stock, either partly or completely manufactured, which are issued to the different departments as needed for their daily routine work.
5. The *Finished Parts Store-Room*, in which the smaller parts of the product, as fast as they are completed, are stored and held until wanted for the process of assembling.
6. The *Pattern Storage Room*. In this department, often occupying several floors of a building specially constructed for this purpose, are stored all patterns for the iron and brass foundries, and also those sent to outside foundries for malleable and steel castings.
7. The *Carpenter Shop*. This is a general utility department making boxes and crates for shipping; doing carpenter work in keeping the grounds and buildings in proper repair, and making necessary changes therein; making and repairing flasks for the foundry; and similar work.
8. The *Paint Shop*. A small room serving little more than as a storeroom for paints and painters' materials, as their work is principally done at various points in the shops, wherever the machines or parts may happen to be.
9. The *Shipping Room*. In a plant building large machinery, the shipping room is simply an office for the shipper, the physical work of shipping being done in the shops, wherever the machine may happen to be at the time.

Referring to the plan given in Fig. 1, it will be seen that the Administration Building is placed in substantially the center of the front line of the plant. The first and second floors of such a building are usually devoted to administrative, commercial, and accounting purposes. The upper floor is usually occupied by the Engineering Department and drafting room.

The three Manufacturing Buildings numbered 1, 2, and 3 are devoted to the various operations of making the parts of which the machinery product is composed. These parts are then sent to the Erecting Building (No. 4).

The system of shop transportation consists primarily of shop tracks and cars, and is extended to the yard, being so designed as to connect all buildings of the plant with one another and with the yard.

It also reaches the railroad tracks at numerous points. Overhead traveling cranes cover the manufacturing buildings, and extend into the erecting building far enough to form a connection with the large traveling crane serving it, by which the large parts of machines are carried from place to place as may be required by the erecting men. This crane serves to load the finished machines upon the railroad cars, when they are to be shipped, the railroad track being extended within the building for this purpose, as shown in Fig. 1.

The Tool Room is given as central a location as possible, and would naturally be near the junction of building No. 2 with the erecting building.

The Experimental Room has no particular place, but is frequently so placed as to be away from the active manufacturing operations, with which it is liable to interfere if too closely related.

The general Store-Room for purchased material may be in the erecting building, but is frequently located, for convenience of communication, nearer the general offices—as for instance, in front of building No. 1.

The smaller parts are stored in a Finished Parts Store-Room, usually located in this building. Thence they are issued to the Assembling Department as required.

The Pattern Shop building will often be composed of three floors. On the ground floor will be the Carpenter Shop and flask making and repairing work. On the second floor will be the pattern-making shop, and on the third floor will be the pattern storage rooms. A large elevator serves all three floors.

The Paint Shop is sometimes located in one of the manufacturing buildings or the erecting building; but as the painting of machine parts and complete machines is generally done in any one of the departments where the work may be, and the paint shop is hardly more than a store-room for paints, a due consideration of the question of fire protection would indicate that it had better be placed in a small building entirely detached from all manufacturing buildings.

The Power House, in the former method of transmitting power by shafting and belting, was located as nearly as possible in the center of the space over which power was to be distributed. Since the advent of electricity and its common use for transmitting power, the question of the location of the power house is relieved from this con-

dition; it may be located at the point most convenient to railroad facilities for receiving fuel, or for obtaining the necessary water for boilers, for fire purposes, etc.

In a plant manufacturing small machines or a kind of product which is shipped in small quantities, it is obvious that the Shipping Room must be convenient to the point from which these goods are to be taken by railroad cars, by boat, or by teams. If most of the shipping is of large machines or articles which must be handled by cranes, the railroad tracks will be run into the erecting building, and the machines loaded there, in order to avoid the expense of extra handling and moving them. This is the arrangement shown in Fig. 1. In this case the shipping room may be in the Administration Building, so as to be convenient to the other office departments. In some kinds of business it is convenient to have the shipping room and general store-room near each other, as there is considerable business done in each that is quite closely related to the other.

The Iron and Brass Foundry is usually located at some distance from the manufacturing buildings, in order that the latter may be as free as possible from the annoyance of smoke and dust. It is connected with the other departments by the system of shop and yard tracks, and the railroad siding track passes through one end of the building as a matter of convenience in shipping castings. There is also a branch track running along the side of the foundry building for the purpose of delivering coke, coal, moulding sand, pig iron, scrap iron, and other foundry materials.

It should be noted that the buildings shown in the plan are located in a compact mass, with considerably less than the usual yard room. In this instance, however, the plan was so drafted to economize space on the drawing. It is the law in some European countries that not over 50 per cent of the area of a manufacturing site shall be covered by roofs. Such a law would be of much value in this country, to prevent the crowding of buildings to such an extent as to be unhealthful to employees.

While factory buildings are frequently erected of from three to to six floors, the modern tendency is to reduce the number of floors in all shops and manufacturing buildings; and in the case of machine shops, a large majority of them are built of only one floor. Some, however, have wide galleries at the side, by which considerable second-

floor space is added; while the central portion remains open to the roof, and supplies ample space for the accommodation of the overhead traveling crane, as well as the necessary added height needed for erecting large machinery.

Foundries are necessarily built of a single floor, although there are several in different parts of the country where moulding rooms are located as high as the third floor. This latter arrangement is usually made for brass moulding, rather than for iron moulding.

Organization of a Manufacturing Plant. Having the design of the plant, and assuming that the required buildings have been erected in accordance with this plan, the next step will be to organize the management both in a general way and also as relates to the various departments usually necessary to inaugurate the business of manufacturing.

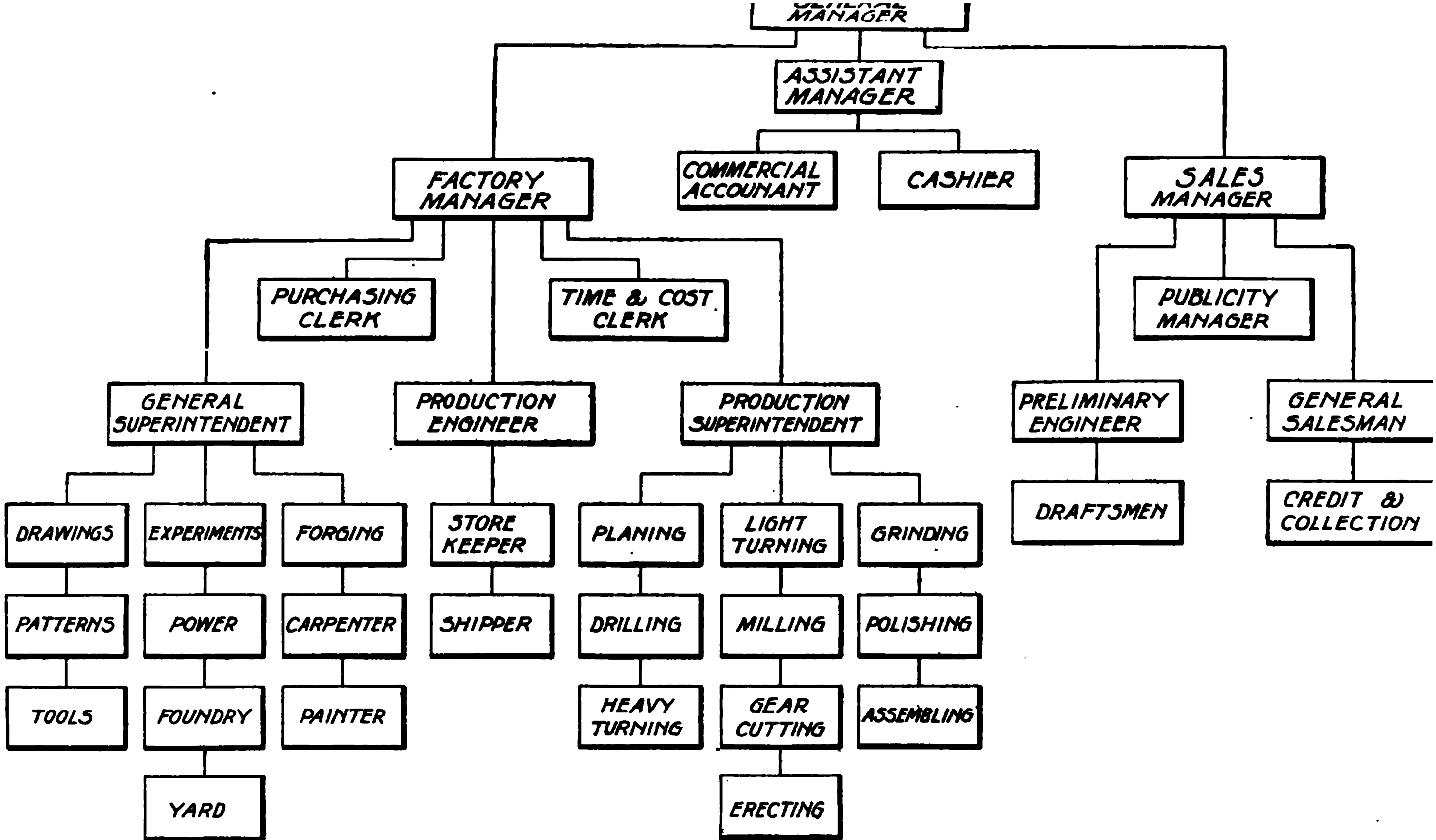
As the scope of this treatise covers only the shop and its management, we need not take up the commercial organization of the company by which it is capitalized and maintained. We shall therefore consider the General Manager as the head of the organization, and proceed to examine the methods usually adopted for the division of authority and responsibilities from him to the actual workmen at the bench, at the machines, and on the floors.

The chart shown in Fig. 2 illustrates the plan of the organization. Nearly all minor officials and office employees, such as bookkeepers, clerks, stenographers, etc., are omitted from this chart, to avoid confusion and to simplify the understanding of the organization plan and its numerous details.

The General Manager has a personal Assistant, and, for his commercial affairs, the service of a commercial Accountant and a Cashier. Other office employees are similar in number, duties, and responsibilities to those in the usual commercial office.

By referring to the chart, it will be seen that the organization is divided into two distinctly different parts. First, that of *production* or *manufacturing proper*; and second, that of *selling* or *marketing* the output produced.

In this case the production division is by far the most numerous and complex. This, however, is not always the case—as, for instance, in the case of a manufacturing concern selling its product through local agents. Frequently the territory over which sales are made is



ig. 2. Chart Illustrating Plan of Organization of a Typical Manufacturing Plant. Showing channels of authority connecting officials and departments.

divided along state lines, and a *District Agent* appointed for each state. These, in turn, appoint the *Local Agents*. This necessitates an organization of hundreds of local agents, supervised by state or district agents, and these in turn by a *General Agent*. Thus a very large organization is built up for disposing of the product.

Another plan is the employment of *Traveling Canvassers*, each having a certain territory to cover, who make their reports to either state or district agents, or to the general agent located at a central point—sometimes at the factory, but not necessarily so.

As competition becomes stronger and net profits smaller, the problem of marketing the product becomes more and more important; greater and more complex selling organizations are necessary; and the expense of selling increases. The advertising organization, or what has come to be known as the *Publicity Department*, is a most important adjunct to the modern manufacturing business; and large amounts of money are annually expended in its maintenance.

In the case under consideration, the selling of the product is in charge of a *Sales Manager*, who has as his office staff the *Publicity Manager*; the *Preliminary Engineer*, and the draftsmen and estimators who assist him; the *General Salesman*, who is in reality the personal assistant to the Sales Manager; and the *Credit and Collection Clerk*.

The *Publicity Manager*, sometimes called the *Advertising Manager*, has charge of all advertising of whatever kind, demonstrations at expositions and at agencies, and, in fact, all work that may be properly comprised under the term "publicity"—that is, keeping the public informed as to the product of the company and its adaptability to meet the needs of the public in the special lines it manufactures.

The *Preliminary Engineer* is in charge of such engineering matters as are necessary upon new work, or work upon which the Sales Manager desires to estimate. It frequently happens that considerable designing and drawing are necessary in this connection, previous to definite orders being given or contracts signed. It often happens that the product of the concern must be changed in certain details so as to adapt it to the uses of various customers, to the different local conditions under which it is to be used, and to the various purposes for which it is to be used. In case an order is given and contracts

signed, the preliminary drawings thus produced become a part of the transaction, and are used by the Production Department in getting out the machinery to fill the order.

The purpose of the *Credit and Collection Office* is to canvass the financial standing of customers and prospective customers; to make collections when necessary to do so; and generally to advise the Sales Manager on these important matters. The official in charge of this office is frequently called the *Credit Man,* and must be a person of peculiar ability in his special line in order to protect the concern from fraud, imposition, and financial losses when dealing with customers of commonly unknown or doubtful financial ability and standing.

The Production Division is under charge of the *Factory Manager,* who has for his personal assistant a *Production Engineer* or *Superintendent,* who plans the productive scheme of the factory and supervises the departmental distribution of the work and the shop operations necessary for the routine work upon it. In a large manufacturing establishment, the Production Engineer will be at the head of a considerable force of draftsmen and clerks comprising what is sometimes called the *Planning Department,* which arranges all operations, shop routine, time schedules, premium rates, and similar matters. The Factory Manager will also have the usual office assistants, and have direct control of the *Purchasing Department,* the *Time and Cost Department,* the *General Store-Room,* and the *Shipping Room.* In some concerns the Time and Cost Department is a part of the Planning Department, as the records of this department cover nearly every kind of information required for the Time and Cost systems.

All other departments of the factory are divided into two general classes. The first comprises the general departments, as follows:

The Engineering Department, or Drafting Room.
The Experimental and Development Department.
The Power Plant, for both the generation and the distribution of power.
The Iron and Brass Foundries.
The Forge Shop and Cutting-Off Rooms.
The Carpenter Shop (including sometimes the Flask Making and Repairing Departments).
The Paint Shop and Painters' Supply Room.
The Transportation Department for shops and yards.

These are under the supervision of the General Superintendent, who has charge of all mechanical matters except those strictly pertaining to production or to the actual manufacturing of the product.

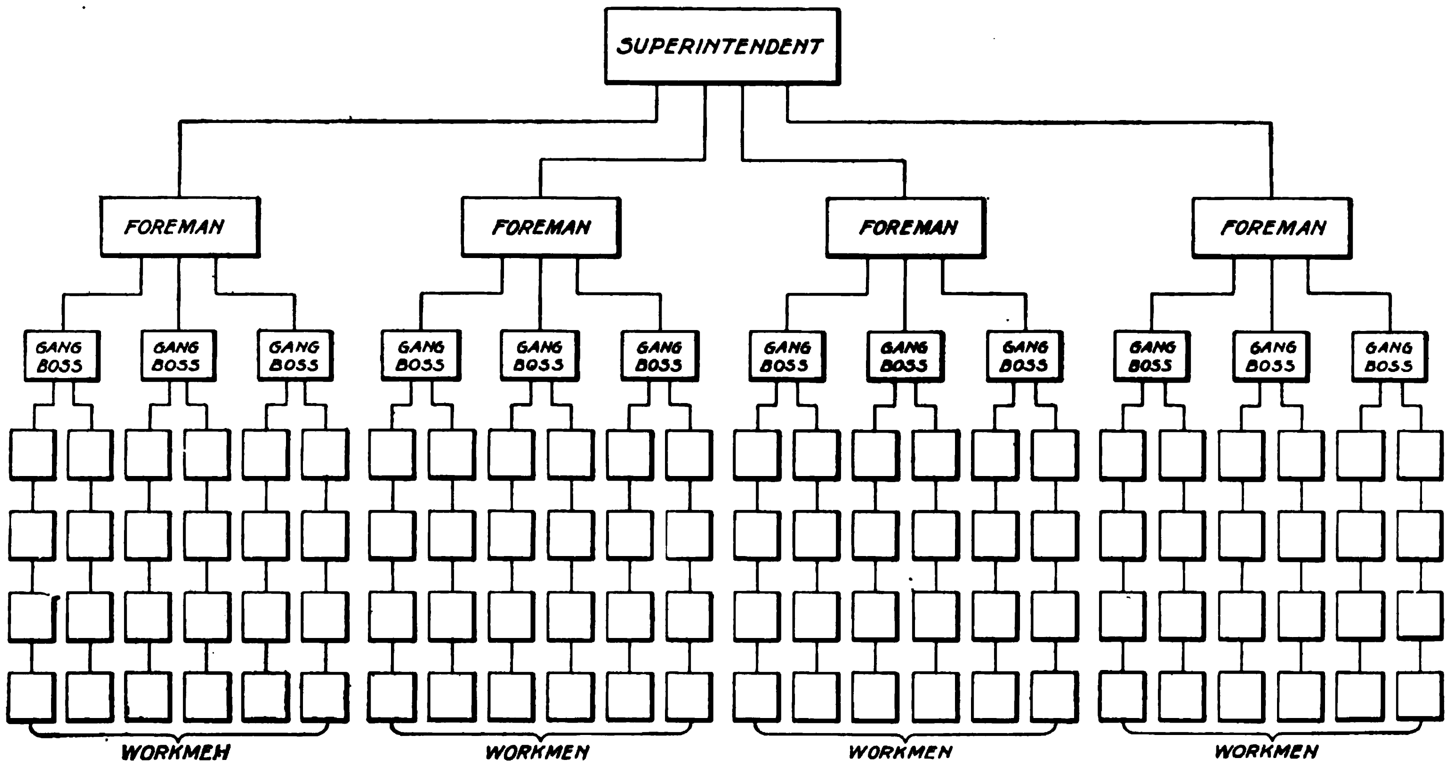


Fig. 8. Chart Showing Official Channels of Communication and Authority from Superintendent to Workmen in a Typical Manufacturing Establishment.

The second general class is that of Production, and will ordinarily consist of the following departments:

The Planing Department, including shapers and slotters.

The Drilling and Boring Department, including vertical, horizontal, and radial drills and boring machines.

The Heavy Turning Department, including lathes of less than 24-inch swing.

The Milling Machine Department, including horizontal, vertical, and special milling machines, profile machines, etc.

The Gear-Cutting Department, for the making of all classes of gears.

The Grinding Department, including cylindrical, disc, and surface grinding.

The Polishing Department, which includes polishing, buffing, etc.

The Assembling Department, in which parts (usually comparatively small) are assembled in groups of related parts and stored, pending the final erection of the machines.

The Erecting Department, in which the entire machine is erected and usually tested, and inspected, receiving the final painting and other finishing work ready for shipping.

Should the character of the product be such as to require it, there will be also a Plating Department, usually located adjoining the Polishing Department.

This class of departments will be under the direct supervision of the *Production Superintendent.*

Each department is in charge of a *Foreman,* who is responsible for the discipline, the work, and the efficiency of the force under him. Frequently the department is large enough to require one or more assistant foremen. Under these may also be *Gang Bosses,* each of whom will have a small force of employees, called *gangs,* for whose work and efficiency he is responsible.

Shop Management. Referring to the Chart, Fig. 2, it will be noticed that the rectangular figures representing different offices, departments, or officials are connected by lines. These are commonly called *lines of authority,* and a careful study of them will show in what manner and through what channels the orders of an official pass to the employees for whose work he is responsible.

Tracing these lines from the head of the establishment through the various offices and officials to the different departments, we get a fundamental idea of *Shop Management.*

This system will be rendered somewhat simpler by reference to the Chart, Fig. 3, which shows the path or official channel of communication and authority from the Superintendent down to the work-

men. It also emphasizes the fundamental idea of all official business passing through the officials in charge of intermediate departments.

Thus, if the Factory Manager desires a certain thing done, he does not give the order to one of the workmen, nor to a foreman, but to the Superintendent. The Superintendent will give his orders to the foreman of the department wherein the work is to be done. If this is a department in which there are gang bosses, the Foreman will give his orders to the proper gang boss, who will select a suitable workman, or as many of them as may be necessary, and instruct them as to the work, and will personally see that it is performed promptly and in the proper manner. When the work is completed, he will report the fact to the foreman, who will in turn report to the Superintendent, who informs the Factory Manager that his orders have been executed.

This process may seem unnecessarily complicated, and in consequence it is sometimes referred to as *red tape*. It is, however, necessary to have a well-defined and properly understood system and channel for all routine business, some of the reasons for which are as follows:

First—It has been said that "no man can serve two masters," and this is quite true in all questions of shop management. Every loyal workman has learned by precept and tradition to look to his immediate superior for all orders and instructions relating to his work, and he naturally and properly resents any attempt to ignore or belittle his legitimate "boss."

Second—As the efficiency of the workmen depends to a great extent upon their loyalty to the management, and as that loyalty can be secured and maintained only by a spirit of justice and fair-dealing to all, including officials and workmen, all authority and responsibility should be sharply defined and properly limited, to the end that the business and work may proceed in an orderly and efficient manner; that all officials and workmen may know when they are within their proper limit of rights; and doing their duties without fear of overstepping their due bounds or interfering with the rights and privileges of their fellows.

Nearly all rules are subject to some exceptions, and the above have theirs. The discipline of the shop, or what is sometimes referred to as the *police regulations*, are expected to be enforced by *all officials at all times*.

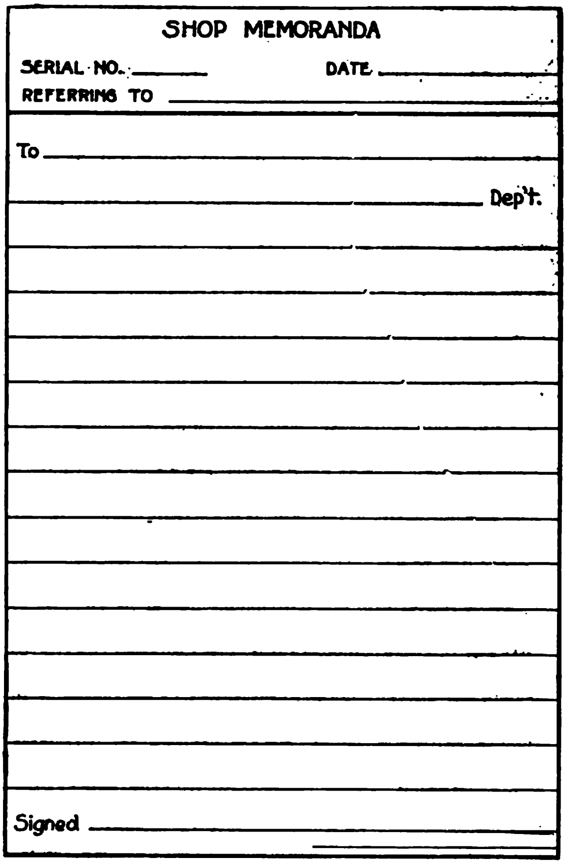
Two of these exceptions are of such a general nature and application that they are here noted.

First—Any official noticing an infraction of the discipline of the plant may call the attention of the employee offending, without regard to the department in which he works, and require him at once to cease violating the rules.

But the official should, as soon as possible, report the matter to the head of the department in which the offending employee works.

Second—Any official noticing work being wrongly done, or material wasted, or machinery obviously injured, or the safety of the workmen, the building, or the machinery endangered, may peremptorily order the action to cease, and at once report the fact to the head of the department or to the Superintendent, as he may judge proper.

Official Communications. For ordinary communications other than General or Special Orders, Production Orders, letters, etc., a written form should be habitually used. The usual form is shown in Fig. 4. These forms are put up in pads of alternate sheets of white and light-tinted paper, the former being perforated at the top so as to be readily torn out while the tinted sheet remains fast at the stub. Both sheets are printed with the same form, and all are serially numbered in pairs of one white and one tinted sheet. Carbon paper is used, the white sheet being written upon and the tinted one receiving the carbon impression. Each official is supplied with these pads, and by their use he always retains a copy of any memorandum or communication he makes to another official or department. The serial numbers are intended to aid in the identification of any memorandum that may have become


SHOP MEMORANDA

SERIAL NO. ______ DATE ______

REFERRING TO ______

To ______

______ Dep't.

Signed ______

Fig. 4. Form for Ordinary Official Communications. A carbon copy is made on tinted paper.

somewhat illegible. The use of these blanks saves any misunderstanding that might occur from giving and receiving verbal orders; and serves to prevent errors and mistakes, and to fix the responsibility for their occurrence upon the party in error.

Successful Management. The spirit of shop management should always be a spirit of *leadership*. This cannot usually be obtained unless the manager possesses natural ability as a leader. Successful military chieftains are examples of this condition. They *lead* the men instead of *driving* them, and the result is a condition of enthusiastic loyalty.

It is also quite as necessary that a leader should be a practical man with sound technical training and practical experience in the business which he undertakes to manage. If he is not thus equipped for his duties, the facts soon become apparent to his subordinates, and his reputation suffers accordingly. The workmen lose confidence in his leadership, and lack enthusiasm in the performance of their duties, going about their work in a listless and perfunctory manner that is very detrimental to the efficiency of the plant.

Still another quality necessary in the successful manager, is the ability to judge men and their capacities for various duties. To get always the right man for the position, the machine, or the job, is a valuable trait in any man who is to direct the work of even a moderate-sized establishment. The larger the plant and the more diversified the business carried on in it, the more valuable and indispensable this characteristic will become. The manager who is continually or frequently changing his subordinate officials, and consequently producing changes in the working force, will always find his duties arduous, and will also find it well-nigh impossible to get the plant up to the degree of efficiency that is to be reasonably expected. The volume of output will continually fall below the normal point, and the quality of the work will also deteriorate. The work of management should be a constant upbuilding of the force, and of development and education along the lines of advancement in the special output of the concern. This cannot be carried on if the composition of the force, or the officials who handle it, are in a transition state of change, doubt, and uncertainty.

There is, on the part of many officials having charge of men, a propensity to interfere too much with workmen and their work, and

thus to hinder rather than help them. While it is quite true that every official from the Gang Boss up to the Factory Manager can, at various times, help the workmen in their allotted tasks by timely advice and suggestions, it is also true that this is a matter that can be easily overdone, until it becomes an annoying nuisance and unnecessarily interferes with the men in the discharge of their legitimate duties.

Workmen are quick to discern when suggestions and advice are well meant and instructive, and when they come as a kind of veiled criticism. The official who permits himself to indulge in this sort of dictation soon falls into a practice of *nagging* that is most exasperating to the men. It is a practice that first weakens and then destroys the official's influence with the men, who obey only from necessity. When this condition exists, the working efficiency of the force is at a very low ebb.

On the other hand, really helpful advice and suggestions, made in a cheerful manner and from a quite apparent desire to assist workmen, will usually meet with a quick and loyal response that argues well for the efficiency of the workmen.

Another point on the road to success, is a patient and interested listening to suggestions that workmen have to make, even though it is on trivial matters. It should always be borne in mind that the workman laboring day after day on the same class, and often on the same kind of pieces, of work, is in a position to discern and to study out many minor improvements in tools and methods which are valuable. A kindly hearing accorded him, the adoption of such suggestions as are practical, with some substantial reward for his study, will encourage not only him but other workmen to study their work and endeavor to find better and more efficient ways of doing it. Thus an active and interested spirit of loyalty is brought about that is one of the most valuable assets of the plant.

The successful manager is he who is enabled to *unite* his working force of subordinate officials and workmen in a complete and loyal organization, all working for the common good and for the success and prosperity of the concern. Having gained this condition, the question of efficient and economical manufacturing is practically as well as theoretically solved.

SHOP METHODS AND RECORDS

From the principles that have been advanced in connection with the subjects of Manufacturing and Shop Management, it will be readily seen that the work of the manufacturing plant of the present day is a very complex matter, and there must necessarily be very complete and carefully formulated plans and systems by which all its operations are regulated, and a somewhat elaborate plan of records by which these operations and their results are recorded and filed.

In formulating the necessary plans for the methods and records of a manufacturing establishment, we must first determine the requirements of the work and decide definitely on what we wish to accomplish. In other words, the conditions must be first examined and analyzed, their various factors studied at their true value, and the requirements determined, so that a general plan of operations may be followed.

These methods shall cover the following subjects:

1. The selection and employment of workmen.
2. The methods of keeping the time of all employees.
3. The manner of paying workmen.
4. The ordering of work into the shops.
5. The routine of passing work through the shops.
6. The method of drawing stock and materials.
7. The ways of keeping and issuing tools.

Importance of Records. Each of these methods will become a part of the routine of the establishment, and the operations carried on under it will be proper matters for regular records made from day to day.

Such records are exceedingly valuable as current information, and, when properly filed, become quite as valuable for reference in the future as for use in current operations.

In all improvements in the working routine of manufacturing operations, there should be previous records by which the present performances may be checked and compared. By this arrangement, it is comparatively easy to ascertain whether or not any improvement is being made, and in what direction it is being made. This knowledge will suggest further plans and betterments. Should the records prove that there are losses rather than gains being made, the warning is equally valuable, and we make haste to better results and greater efficiency in the work.

Thus, whether the plans and methods in use are really successful, or quite the reverse, it is of the utmost importance that we should know by prompt and accurate records just what the results are, in order to keep in close touch with the progress of events, and that, when plans do not produce the favorable results expected and desired, the information may be promptly available, the warning be heard, and plans altered or amended until they bring about a successful routine in the manufacturing operations.

Selection and Employment of Workmen. This is an important matter, since it costs money to introduce new men in any business,

APPLICATION CARD				
NAME ________			DATE ________	
ADDRESS				
AGE	MARRIED SINGLE	NATIONALITY	WAGES ASKED	EVER EMPLOYED HERE ?
LAST EMPLOYER		KIND OF WORK		WHEN
PREVIOUS EMPLOYER		KIND OF WORK		HAVE BEEN EMPLOYED FOR ________ YEARS
KIND OF WORK WANTED				
REFERENCE				
EMPLOYED				

Fig. 5. Application Card.

and requires from a day or two to several weeks for the new man to become sufficiently accustomed to his work and surroundings to be of the same value as the man who is perfectly familiar with the shop, the routine and methods of work, and the foreman under whom he works.

It is therefore necessary to go about this matter in a methodical manner, and to keep records of:

(*a*) All persons making application for employment.
(*b*) All persons regularly accepted as employees.
(*c*) Individual records of all regular workmen.
(*d*) All employees who leave the employment of the company.

To accomplish these results, the official whose duty it is to employ men will fill out, or will have a clerk fill out, an *Application Card* of the form shown in Fig. 5, for each person applying for a position. It will

be noticed that it is important to know whether the applicant has ever been employed in this establishment previous to the present application. If so, his record can be readily referred to for information as to the desirability of employing him again. It is also necessary that the record of his last employer be known, and frequently of the employer previous to the last, as these matters will also be taken into consideration in determining his fitness for the position for which he applies. It is also necessary to know how many years he has been employed in manufacturing establishments, as this fact, taken in consideration

EMPLOYMENT CARD

NAME ______________________ DATE ______________

ADDRESS ______________________

AGE	MARRIED SINGLE	NATIONALITY	WAGES PER	EVER EMPLOYED HERE ?

LAST EMPLOYER	KIND OF WORK	WHEN

BY WHOM HIRED	KIND OF WORK

DATE TO BEGIN WORK	FOREMAN

APPROVED

______________ SUPERINTENDENT

Fig. 6. Employment Card.

with his age, will frequently furnish information upon which to base judgment as to his fitness.

The Application Card, being on file, is available for the use of such foremen or other officials as may be in need of workmen. Should the applicant be decided to be available, after consultation between the official to whom application was made and the foreman desiring to increase his force, the applicant will be sent for, and employed at a rate mutually satisfactory, and an *Employment Card* of the form shown in Fig. 6 filled out. This will repeat some of the information contained on the Application Card; but it is necessary to have two cards in any event, as the information must be filed in separate drawers.

The Employment Card will also give the name of the official employing the man, as well as that of the foreman under whom he is to

work, the kind of work he is to perform, and when he is to commence work. It will also require the approval of the Superintendent or Factory Manager, as the case may be, to make it valid and operative.

The applicant having become one of the regular employees of the concern, a third card is made out for filing in the *List of Employees* drawer. This will be upon the form shown in Fig. 7, and is called a *Service Card.* It will be noticed that each of these three cards is headed with the name and address of the person whom it represents.

The Service Card gives the department in which the employee is to work, the kind of work which he is to do, the date he begins work,

SERVICE CARD

NAME				
ADDRESS				
DEPARTMENT				
KIND OF WORK				
DATE BEGUN	RATE	PAY RAISED	PAY RAISED	PAY RAISED
TRANSFERS				
QUIT	REASON			

Fig. 7. Service Card.

and his rate of pay. Spaces are also provided for noting the amount and date of any increases in his rate, and for the record of a transfer to another department should he be moved, as is frequently the case with new men who may not be quite adaptable to the kind of work first attempted, but entirely satisfactory at some other class of work.

A space is also provided for noting the date of the workman's leaving the employ of the company, and also for giving the reason for it. This will be valuable information in case the workman should subsequently apply for employment. When an employee leaves the service of the company, his Service Card is removed from the List of Employees drawer, and placed in a fourth drawer labeled *Discharged or Quit,* being held there for future reference.

Individual Record of Standing. In many well-conducted manufacturing establishments, it is customary to keep a record of the standing of the men as rated each month, as a valuable reference in cases of proposed promotion, increases in pay, reliability for special work and positions of responsibility. Various methods of marking the records of the men each month have been tried, but the simplest method is to use the number 100 for perfect, and to divide it as follows:

Good workmanship	50
Punctuality in reporting for work	30
Deportment during working hours	20
Total	100

INDIVIDUAL RECORD							
NAME						NO.	
YEAR							
MONTH	MARK	MONTH	MARK	MONTH	MARK	MONTH	MARK
JAN.		AUG.		JAN.		AUG.	
FEB.		SEP		FEB.		SEP	
MCH.		OCT		MCH.		OCT	
APL.		NOV.		APL.		NOV.	
MAY		DEC.		MAY		DEC.	
JUNE		TOTAL		JUNE		TOTAL	
JULY		PER CENT		JULY		PER CENT	

Fig. 8. Individual Record Card.

Demerits are marked off as to workmanship, by the foreman, according to his judgment aided by the Inspector's reports of the work done by the man.

Punctuality is judged by the number of times late, each instance reducing the mark by one unit. As the workman enters the shop twice a day, morning and afternoon, assuming 26 working days in the month, a practical disregard of punctuality soon reduces his record in this respect to zero.

Deportment is judged by the Foreman, who also takes into account occasions on which the workman may have been reported for violating the regulations in this respect.

A *Record Card* is shown in Fig. 8, upon which monthly records are kept. The total for any period, divided by the number of months covered by the record, will give the percentage of a perfect record. This card provides for a record for two years.

If it seems advisable to do so for special reasons, a similar card may be formulated covering the six working days of the week. A year's record in this form may be entered on a card 4 by 6 inches, by arranging the horizontal and vertical ruling for that purpose.

Such a record may be profitably kept of the work of the office force, as well as of the men in the shops. It will be valuable in many ways in judging of the availability of the men for special work, as well as for promotion.

Necessarily such records should be very carefully kept; otherwise there is liable to be serious injury done to the working reputation and integrity, as well as reliability, of the men.

The Employment Agent. In large concerns, an official is regularly appointed as an Employment Agent, and it is his duty to keep the office and the shops supplied with competent men engaged at reasonable wages. He must therefore keep in close and accurate touch with the labor market, for the same reasons that the purchasing agent must know the state of the market for material and supplies. He must know how and where to reach workmen of the different classes whenever he is called upon to furnish them.

While ordinary laborers may nearly always be obtained from the daily applications made at the office, skilled men must be hunted up; and it is not usually easy to find just the man with the qualifications desired.

When men are wanted for positions above the average skilled workmen, the best and most promising will be nearly always distributed among the present employees who are deserving of advancement. To promote one of them, rather than hire some man from outside the organization, is usually good business policy. The man and his abilities are generally well known, while a stranger is always an unknown quantity. The men, being acquainted with the man, will be pleased to see him get the deserved promotion; and it is always wise to consider the popularity of proposed orders affecting the working force. The man himself will feel his added responsibilities much more than an outside man will, and will generally work harder to suc-

ceed in his new position. Therefore it is always best to give the first chance to present employees who have been faithful to the responsibilities thus far placed upon them.

It will be found that in most of the departments there are employees who from one reason or another are doing work quite below their real capacity, hoping that later on there may be better opportunities for the coveted position. The Employment Agent should know the men of the force, and their abilities, so as to take advantage of these conditions. A man may be needed by a foreman in one department who is not aware that in a neighboring department may be just the kind of man he wants. The Employment Agent should know where to find the man at once.

Again, one department may, from the conditon of the work, be short of help, and may request the Employment Agent to hire a certain number of men of certain qualifications and abilities. At the same time, there may be another department in which there are more men than can be used to advantage. An arrangement for the temporary or permanent transfer of some of these men will be a great help to both departments, and will have the added advantage of keeping good men permanently employed.

If a workman feels that his employment is permanent, and that there are fair opportunities for advancement, this will be the surest way to hold him faithful and loyal to the interests of the establishment; and the conditions that bring about this condition of mind in him will also draw other good men who will be glad to be counted as among those faithful to a company which appreciates their services and which will look to their interests as they consider those of their employers. The result will be that these men will give their best services, and even be on the alert to further the interests of the employer who has favored them. Thus a strong working organization is built up, which becomes one of the best and most valuable assets of the company.

Time Keeping. As cost of labor is usually greater than any other in the manufacturing plant, and frequently greater than all other factors in the cost of manufacturing, it is very important that the records pertaining to this expense be properly planned and accurately kept.

Various methods have been adopted and used for this purpose. Some of the more prominent plans will be given. They are each

adapted to some certain kind or class of work, and it will often be found that in practice still different forms must be devised in order to meet the existing conditions.

There are three methods of recording the time of employees—namely:

1. By entering the time in a book or upon cards, by a Time-Keeper.
2. By entering the time upon cards by the workman himself.
3. By stamping the time upon cards by the workman in a time-recording clock.

The first of these methods is the oldest form, and has now to a great extent gone out of use.

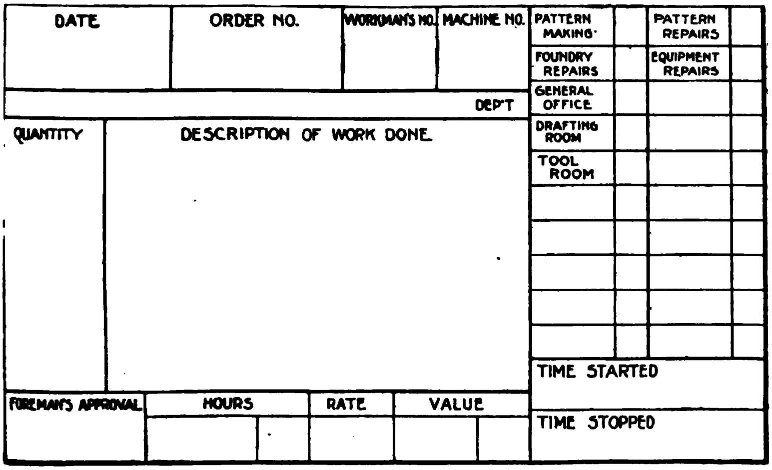


Fig. 9. Pattern Shop Time Card.

A large majority of the work of a manufacturing plant requires that the time worked by the employees shall be registered twice. That is, one entry shall be of the *day time* (time paid for *by the day*), which necessitates the recording of the total number of hours worked each day; the second entry shall record the *job time* (the time worked upon the different jobs during the day). This second entry is sometimes called *Time Distribution,* since the employee's time is distributed over the different jobs upon which he has worked.

Time-Card Forms. This work is sometimes done by means of time cards as shown in Figs. 9, 10, 11, and 12, which are given as characteristic examples of these methods. These cards are of different tints as a convenient method of recognizing them.

Fig. 9 is yellow, and is used in the Pattern Shop.

Fig. 10 is chocolate-colored, and is used in the Forge Shop.

Fig. 11 is blue, and is used by the Carpenters and Flask Makers.

Fig. 12 is white, and is used in the Machine Shop.

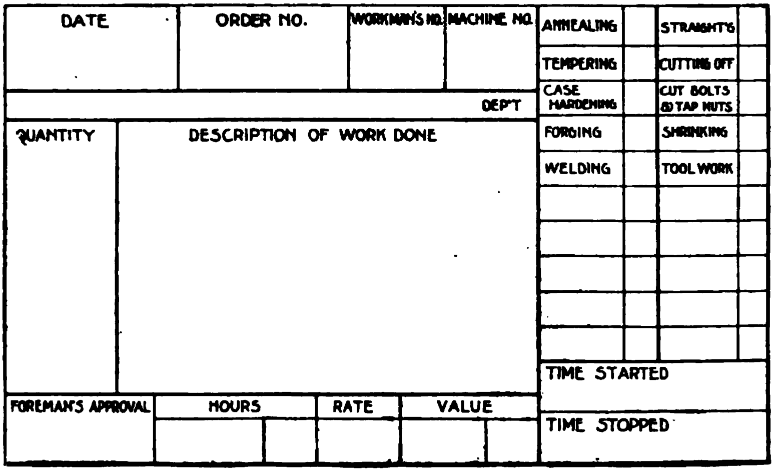

DATE
ORDER NO.
WORKMAN'S NO.
MACHINE NO.
DEP'T
QUANTITY
DESCRIPTION OF WORK DONE
FOREMAN'S APPROVAL
HOURS
RATE
VALUE
ANNEALING
STRAIGHT'G
TEMPERING
CUTTING OFF
CASE HARDENING
CUT BOLTS & TAP NUTS
FORGING
SHRINKING
WELDING
TOOL WORK
TIME STARTED
TIME STOPPED

Fig. 10. Forge Shop Time Card.

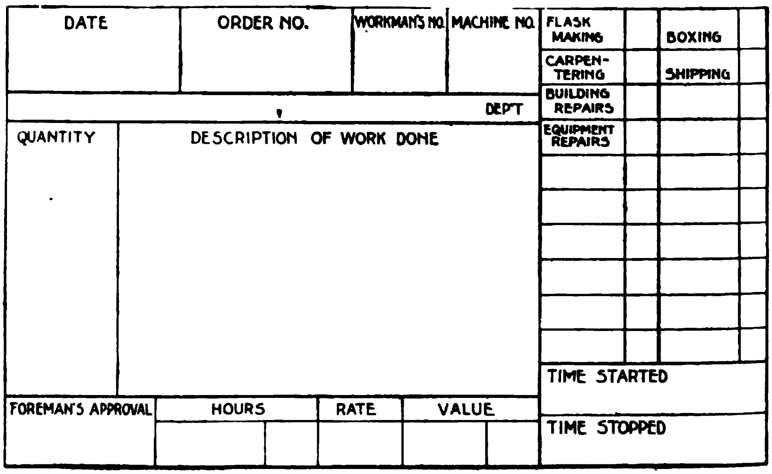

DATE
ORDER NO.
WORKMAN'S NO.
MACHINE NO.
DEP'T
QUANTITY
DESCRIPTION OF WORK DONE
FOREMAN'S APPROVAL
HOURS
RATE
VALUE
FLASK MAKING
BOXING
CARPENTERING
SHIPPING
BUILDING REPAIRS
EQUIPMENT REPAIRS
TIME STARTED
TIME STOPPED

Fig. 11. Time Card for Carpenters and Flask Makers.

Similar card forms may be devised for any other department of a plant, or for the departments of plants doing entirely different work.

When these cards are used as a means of distributing the time to the various jobs or orders in force in the shop, the *day time*, from which the pay-roll is made up, is usually recorded on a strip of paper in a time clock, the operation being performed by each employee as he passes into the shop morning and afternoon, and when leaving at noon and night. Passing to the clock, the workman swings a lever to his individual number, and presses in a knob, whereby the exact time of the operation is recorded upon a slip of paper, a ribbon, or a disc within the clock.

In other forms of time clock, an individually numbered key is inserted in one of the individually numbered holes, turned around, and

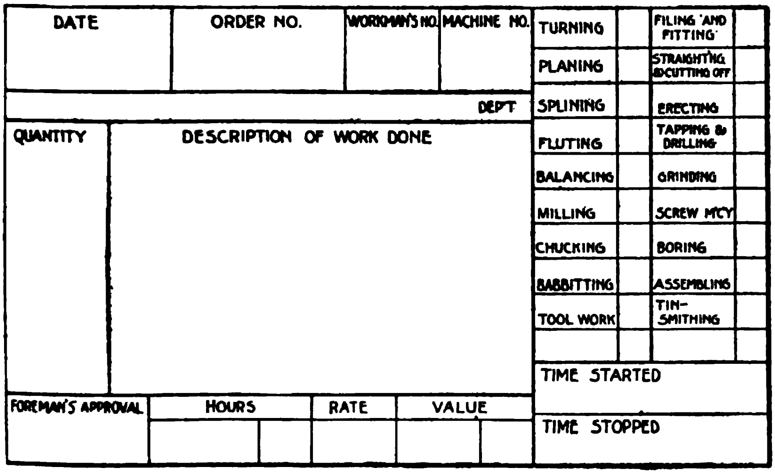


Fig. 12. Machine Shop Time Card.

withdrawn. The time is recorded in a manner quite similar to that used in the case just described above.

The four forms for time cards shown are quite similar, the difference being in the list of operations given at the right-hand end of the card.

At the top of the card are spaces for the date, order number, workman's number, and the number of the machine upon which he works (provided the work is done on a machine). In the next space, the name of the department is given. This is followed by spaces for the *quantity*—that is, the number of pieces, feet, or inches of such material as is designated in this way, or the number of pounds in weight of the material. Then comes a brief description of the work.

Opposite each of these is a square in which the workman can indicate the particular kind of work he has been doing, by marking an X. Thus the form shown in Fig. 9 contains the following classes of work—namely, Pattern Making, meaning new pattern work; Pattern Repairs, referring to repairs charged to the job; Foundry Repairs, or repairs to patterns or fixtures the expense of which is to be charged to the Foundry Department; Equipment Repairs, referring to pattern shop equipment; General Office, consisting of small jobs of equipment and maintenance that are better done by a pattern maker than by a carpenter; Drafting Room, similar new work and repairs, such as drafting boards, angles, etc.; Tool Room, similar work chargeable to this department, such as boxes or cases for special tools, and work not entrusted to a carpenter.

Whatever may be the kind of work the employee is engaged upon, he checks it as described; and after the words "Time Started," he notes the hour and minute he begins work. When the job is completed, he notes the time after the words "Time Stopped." The elapsed time, the rate, and the value are filled in by the time clerk.

This card is turned in to the foreman or dropped in a box provided for that purpose, it having been approved by the foreman of the department in which the work is done. It then goes to the time clerk.

As each workman has a card for each different job and for each day, it follows that all the job cards for a single day must aggregate the same amount of time as that indicated on the stamped record within the recording time clock. Discrepancies of this kind are investigated, and the time distribution readjusted until satisfactory, the foreman of the department usually being consulted in the case.

Recording-Clock Time-Cards. Recording time clocks are also made which operate automatically to produce changes in the position of the card dropped into a receptacle provided for the purpose, such, that when a lever is manipulated, not only is the exact hour and minute stamped upon the card, but it is stamped in its proper place upon the card so as to correspond with the proper day of the week and also indicate whether forenoon or afternoon. The horizontal changes of position are made by hand, previous to manipulating the operating lever.

K ENDING ______________________ 190

____

E

____

DAY		IN	OUT	LOST OR OVERTIME IN	LOST OR OVERTIME OUT	TOTAL
	A.M.					
	P.M.					
	A.M.					
	P.M.					
	A.M.					
	P.M.					
	A.M.					
	P.M.					
	A.M.					
	P.M.					
	A.M.					
	P.M.					
	A.M.					
	P.M.					

TAL TIME ______________________ HRS. ______

TE ______________________

TAL WAGES FOR WEEK $ ______________________

Fig. 13. Day Time Card.

THIS SIDE OUT

NO. 105

NAME ______________________

Fig. 14. Back of Day Time Card.

ORDER NO. ____________________

DATE, ____________________

EMPLOYEE NO. ____________________

MACHINE NO. ____________________

ARTICLE, ____________________

OPERATION, ____________________

DAY		IN	OUT	IN	OUT	TOTAL
F	A.M.					
	P.M.					
S	A.M.					
	P.M.					
S	A.M.					
	P.M.					
M	A.M.					
	P.M.					
T	A.M.					
	P.M.					
W	A.M.					
	P.M.					
T	A.M.					
	P.M.					

TOTAL HOURS ____________ MIN. ________

RATE ____________________

AMOUNT ____________________

Fig. 15. Job Time Card.

A form for a regular Day Time card is shown in Fig. 13. The days of the week are given, and each divided by horizontal lines into spaces for forenoon and afternoon. Vertically the dividing lines divide spaces for the time the workman comes IN, goes OUT, and for similar records for lost time or overtime, as the case may be.

At the top of the card is the date, generally given as the last day of the week for which time is made up. This is followed by the number and name of the employee. Following the table prepared for the time stampings, is a space for the total time, the rate, and the amount due for the week.

The back of the card is shown in Fig. 14, and is plain except at the top, which is printed in large and plain type "This Side Out," as employees are liable to introduce the card with its face outward. For convenience the employee's number and name are given on this side as well as on the face.

By the above method of time recording, *all* employees will use the regular Day Time card. Such employees as work on the regular production orders, and on work properly chargeable to them, will in addition to the Day Time card use a Job Time card, of the form shown in Fig. 15. This card is provided with spaces at the top for the order number, date, employee's number, machine number, article or piece upon which the work is being done, and the name of the operation that is being performed. The body of the card has the same spaces for the recording stampings. It will be noticed that the card shown in Fig. 13 runs from Monday to Sunday, inclusive. This is the usual form, but in some shops the fiscal week ends on different days of the week. In the job card shown in Fig. 15, it ends on Thursday.

In the use of these job cards, a card is made out for each job or order, without regard to the number of different jobs an employee may have in a day. The aggregate of the time shown on all these cards for a day must aggregate the amount shown on the day time card from which the pay-roll is made up. Thus each card acts as a check on the other, and accuracy is insured to a considerable degree.

When the work for which the job time is issued has been completed, and the card receives its final stamping, it may be turned over to the foreman, who will send it to the Time Clerk. This gives the foreman an opportunity to look it over and correct any mistakes that may have been made. In some shops the card is dropped into a box marked *Job Time Cards—Completed,* whence it is gathered up with others, by the Time Clerk. Coming into the possession of the Time Clerk, he will check it up, together with such others as the workman may have used on the same day, in order to ascertain if the total time on the job cards for the day equals that shown on the day time card.

When the Time Clerk has compared the cards, he will send the job cards to the Cost Clerk, who will enter the amounts in a *Job Time Summary* book of the form shown in Fig. 16. On this blank, the number, name, and rate of each man are written. The succeeding columns are headed with the various current order numbers. Entries are made opposite the man's name, of the pay-roll value of the time he has worked on the various orders or jobs for the day. The total, carried out in the extreme right-hand column, represents his pay for the day. The totals at the bottom of the job columns represent the value of the time spent on each order, for the day. The work is

JOB TIME SUMMARY

FOR WEEK ENDING ________ 190

NO.	NAME	RATE	JOB NUMBERS																						TOTAL
		TOTALS																							

Fig. 16. Job Time Summary.

checked as correct when the sum of all the totals of the right-hand column is exactly equal to the sum of all the totals at the foot of the columns.

The entries in this book are made by quite young clerks, who handle only these job cards and books as their daily tasks, and who become very expert, accurate, and rapid at this work. The totals are carried by the Cost Clerk or one of his assistants to the *cost ledger*, in which the costs of both labor and material, as well as all expense charges, are brought together. Sometimes this work is done upon cards, each one representing an order and containing in brief and condensed form all the charges of whatever kind made against the order.

Methods of Paying Employees. The methods by which pay-rolls are made up and the employees paid, are important; and whatever plans are adopted, they should realize the following desirable requirements:

1. The record of amounts due the men should be absolutely accurate and in accordance with the rates at which the men were employed, subject (*a*) to such modifications as may be made by reason of properly authorized changes in rate; (*b*) to such modifications as may be made from week to week by overtime work, or by the operation of methods of "piece work," "premium work," or any of the several plans for rewarding exceptionally efficient work; (*c*) to such deductions as may properly be made on account of advance payments that have been made upon due authority.
2. The methods of making up the pay-roll and paying the men should secure promptness in this work, so that the pay of the employees may not be held back for an unreasonable length of time pending the necessary clerical work.
3. The methods of payment should be such that no workman can know the amount paid to any other workman.

To accomplish the results desired in the first requirement, if the amounts due the men are made up from the time recorded by the men themselves—that is, in a recording clock—is a comparatively easy task, since it is principally a matter of mathematics, with a strict attention to details.

Changes in rate of pay do not usually take effect until the week following that in which the order is given. This order will be in the form of a request by the foreman of the department in which the workman is employed, stating the reasons for the increase. This is sent to the Superintendent or Factory Manager for approval. If approved, it is then sent to the Pay Clerk, who files the notice for future reference and makes the required change on his pay-roll.

Premium work rates will be made up by the foremen of the departments, and approved by the Superintendent, in smaller shops. In large plants the rates will be made up by a clerk in the Production Department, and approved by the Production Engineer. In either case they will be sent directly to the Pay Clerk.

Advances to men will be made only in special cases, upon a written request from the foreman, stating the reasons and approved by the Superintendent.

The second requirement can be met by having the time cards of the style used in recording clocks (as shown in Figs. 13, 14, and 15). The convenience and rapidity of making up the time of these cards is apparent from the fact that the record of the entire week is contained upon the face of one day time card, lost time being checked only in red ink in the total column at the right, and the sum of the amounts of lost time being subtracted from the regular working time for the week Thus, if the working time is 55 hours per week, and the lost time was ½ hour one day and ¼ hour another, making ¾ hour, we subtract that from 55, leaving 54¼ hours as the time for the week. This is much more rapidly done than to carry out the total time for each day and add up these totals for the six days of the week.

The *Pay-Roll Sheet* or *Pay-Roll Book* is shown in Fig. 17. This is now frequently made as a loose sheet or such number of sheets as may be necessary to contain all the names, frequently as many as 50 names on the sheet. Upon examination of this printed form, it will be seen that the regular time is divided into *productive* and *non-productive* labor. This is for the purpose of ascertaining what portion of the labor is applied directly upon the product, and what portion is applied indirectly, such as foreman, clerks, general laborers, etc., whose work is classed as non-productive.

The amount of the regular time is computed, and entered in the column headed *Amount*. If there is an amount due in premiums, it is entered in the next column, and the two amounts added in the column headed *Total Amount*. In the next column is entered the amount of any advances that may have been made, which is deducted from the total amount, leaving the net *Amount Due*, which is entered in the next column. This amount is paid over to the employee, who signs his name in the space under *By whom received*, and the operation is complete. The men's numbers are placed at the extreme left hand and

PAY ROLL

FOR WEEK ENDING ____________ 190

PAYMENTS MADE ____________ 190

NO.	NAME	RATE	DEP'T	HOURS PROD.	HOURS NON-PRO.	TOTAL HOURS	AMOUNT	PREMIUM	TOTAL AMOUNT	ADVANCED	AMOUNT DUE	BY WHOM RECEIVED	NO.

CERTIFIED AS CORRECT

APPROVED

PAID

right hand of the form as a matter of convenience in rapidly handling the work of paying off.

When the pay-roll has been completely made up, it is submitted to the Superintendent, who certifies as to its being a correct list of men actually employed, and to the rates of the different men. It is then submitted to the Factory Manager for approval. After the amounts due the men are actually paid and receipted for, the Treasurer certifies the fact, and the pay-roll becomes a voucher for the amount represented on the roll.

Giving Orders for Manufacturing Work. As ordinarily considered, orders are of two general classes, namely:

<table>
<tr><td>NO.</td><td>PRODUCTION ORDER</td><td>DATE</td></tr>
<tr><td colspan="3">Please execute this order, charging all Labor and Material to above order number.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Complete the work by</td><td>Completed</td><td>Approved
FACTORY MANAGER</td></tr>
</table>

Fig. 18. Production Order.

1. *Production Orders*, by which the production departments are set to work manufacturing some regular or special product which is to be sold to customers.
2. *Plant Orders*. These orders relate to the repairs and maintenance of the grounds, buildings, and equipment of the plant, and to new additions to and alterations of the same.

Both of these classes originate with the Factory Manager, who receives instructions as to all important orders from the General Manager of the company, who will authorize and keep in touch, not only with the production of the plant, but in a general way with all changes, improvements, and maintenance expenses of the establishment.

Production Orders. Fig. 18 shows the form of a regular production order. This card or blank is made of such dimensions as the kind of manufacturing business to which it pertains may require. It is customary to use a card 4 by 6 inches; but if such is to be written upon the central space in order to describe the work properly, it should be somewhat larger. The principal features of this form are spaces for the title of the card, the order number, and date. At the bottom is given the date when the work is expected to be completed, and the date of its actual completion. These dates are important as

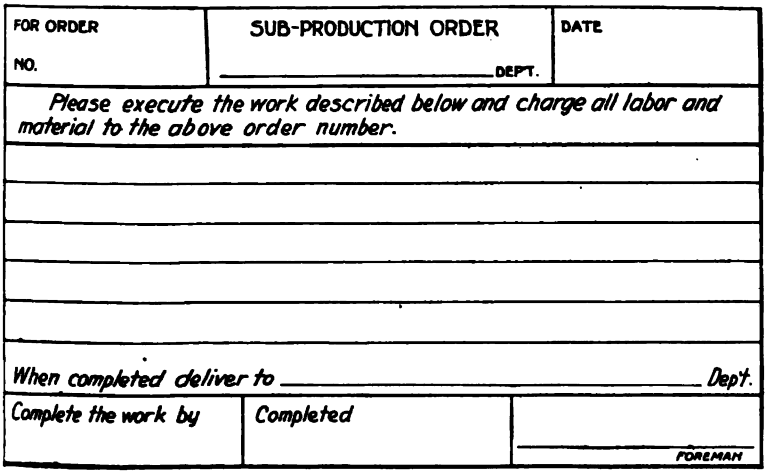

FOR ORDER NO.
SUB-PRODUCTION ORDER
DEPT.
DATE
Please execute the work described below and charge all labor and material to the above order number.
When completed deliver to ______ *Dept.*
Complete the work by
Completed
FOREMAN

Fig. 19. Sub-Production Order.

a matter of reference in considering the promptness and efficiency of the departments where the work has been done.

The work to be done is briefly described in the central portion, together with such references to sets of drawings, etc., as may be necessary to render the terms of the order indisputably certain. This order is signed by the Factory Manager and sent to the Superintendent. In a large concern it is sent to the Superintendent of Production or the Production Engineer, according to the particular manner of the organization of the official force.

In any event the order is turned over to the official having charge of production, who will make out *Sub-Production* orders (Fig. 19) for each department in which the particular work described upon the orders is to be done. A time limit is given for the completion of

the work, and a space provided for the actual date of completion. They are not signed when issued, but are dated and signed by the foreman when the work is completed.

Plant Orders. As has been described, plant orders are those necessary for the changes, improvements, and maintenance of the plant and equipment. In some establishments there are two series of orders, namely: (*a*) those for improvements and maintenance of the *plant* proper—that is, grounds and buildings; and (*b*) improvements and maintenance of *equipment*. This is a very proper and natural division. These accounts may be subdivided to a very great extent, but not with corresponding value.

Plant orders are usually issued by the Superintendent (or General Superintendent, in a large plant), and are returnable to him, as

NO.	PLANT ORDER ________ DEPT	DATE
Please execute the work described below and charge all labor and material on the back of this card and return it to me.		
To be completed by	*Completed*	________ SUP'T

Fig. 20. Plant Order.

will be seen upon reference to the form shown in Fig. 20. This order is usually directed to a certain department. If more than one department is involved in the work, a separate order is issued to each. The general form of the order is the same as in the two preceding ones, the instructions being changed to suit the nature of the case.

On the back of this order is a form for entering the cost of material and labor, as shown in Fig. 21. The dates upon which each item (or group of items) of material is furnished, are given, as are also the dates for the various items of labor, although the work of an entire

week may be entered upon a single line. On the second half of the card, space is provided for the totals of both material and labor cost; also such general expenses in the form of a percentage or such other apportionment as may be authorized, are entered.

By this method the order for the work, and a summary of the expense of executing the order, are contained upon the same card, which is very convenient for future reference and comparison.

Storing and Issuing Stock and Materials. The orders having been put in force in the shop, the next step is to obtain the necessary material or stock with which to do the work.

All purchased stock, material, and stores are turned over to the

DATE	MATERIAL	VALUE		DATE	LABOR	HRS	VALUE	
					TOTAL LABOR			
					TOTAL MATERIAL			
					EXPENSES			
	TOTAL MATERIAL				TOTAL COST			

Fig. 21. Back of Plant Order Shown in Fig. 20. For entering cost of material and labor.

General Storekeeper, whose duty it is to classify them, store them properly, and issue them only on properly authorized requisitions. A large portion of his stock he obtains by making requisitions upon the Purchasing Agent.

To account properly for the receipts and issues of this stock so as always to have on hand what is wanted, and at the same time to avoid carrying an unnecessarily large stock of any of the articles in store, he uses a *Stock Ledger Card* of the form shown in Fig. 22. This gives the name of the article listed, and its dimensions, weight, etc. At the right of this are entered the maximum and the minimum quantities to be kept in stock. Whenever the stock on hand is re-

STOCK LEDGER CARD ______									MAX. ______	
ARTICLE									MIN. ______	
Received		Issued								
Date	Amount	Date	Amount	Date	Amount	Date	Amount	Date	Amount	Total
Forward										
Total ______		Forwarded ______						Total ______		

Fig. 22. Stock Ledger Card. Same form is printed also on back of card.

REQ. NO. ______	REQUISITION	DATE ______
STORE KEEPER: *Please issue for use on Order No.* ______ *the following Material.*		
QUAN.	DESCRIPTION	
DATE ISSUED ______	______ DEPARTMENT.	______ FOREMAN. ______ STORE KEEPER.

Fig. 23. Form of Requisition.
Carbon copies of the entries are made on the Invoice form, Fig. 24.

duced to near the minimum quantity, the Purchasing Agent is requested to order enough more to bring the quantity up to the maximum.

In making requisitions upon the Purchasing Agent, the Storekeeper must take into consideration the length of time necessary to obtain the article wanted. Wire nails, wood screws, and such articles can usually be obtained in 24 hours, while brass tubing may take

three weeks. Iron castings can be had in two days, while steel castings will frequently require six weeks.

When articles are *received in stores*, the date and quantity will be entered under the heading *Received*, and other quantities added to these as received. Articles issued will be charged under the heading *Issued*, giving the date and amount. The quantity on hand may be quickly ascertained by adding the quantities received and the quantities issued, and subtracting the sum of the issues from the sum of the receipts.

As most articles are purchased in considerable quantities and issued in small lots, there will be few entries of receipts and a large

REQ NO. ______	INVOICE		DATE ______
I have issued to apply on Order No. ______ the following Material.			
QUAN.	DESCRIPTION	RATE	VALUE
DATE ISSUED ______	______ DEPARTMENT	______ FOREMAN ______ STORE KEEPER	

Fig. 24. Form of Invoice.
Entries are made by means of carbon paper, duplicating those made on the Requisition form, Fig. 23.

number of entries of issues; therefore the greater portion of the card is devoted to records of issues. The card is printed with the same form on both sides; and when the spaces on the first side are filled, the account is balanced, and the results carried to the opposite side.

These cards are kept in filing drawers, where they are located in alphabetical order by the names of the articles they represent.

A foreman, on receipt of a regularly numbered and authorized production order or sub-production order, is thereby authorized to make requisition for such stock and material as may be necessary to use in the execution of the order. This he will do by the use of the

Requisition shown in Fig. 23, entering the order number and date, and specifying the quantities and descriptions of the articles required. Ordinarily each requisition will contain but one article or class of articles. At the bottom of the requisition, the foreman will enter the name of his department and his own signature.

These requisition blanks are made up in pads (the form shown in Fig. 23), of white paper alternating with tinted paper on which is the *Invoice* form shown in Fig. 24. This latter form has its ruling and other principal features identical with the form of the requisition, so that by the use of carbon paper the foreman makes a duplicate on the Invoice blank, of the order number and date, the articles required, the name of his department, and his own signature.

MATERIAL RETURNED

TO CREDIT OF
ORDER NO. ____________ DATE ____________

STORE KEEPER *The following Material is returned as not necessary for use on the above order.*

QUAN.	DESCRIPTION	RATE	VALUE	

RECEIVED THE ABOVE

____________ STORE KEEPER: ____________ FOREMAN.

____________ DEPT.

Fig. 25. Returned Material Card.

When the Storekeeper issues the articles, he first enters upon the requisition blank the date issued, and then passes it to his assistant, who notes the issue on the *Stock Ledger Card*, and then places it on file. The Storekeeper will enter on the invoice the rate and value of the articles issued, and the date of issue, and will sign it under the foreman's signature. He will send it, with the articles issued, to the foreman, who will in turn make it a part of his report of material used.

When the work on an order is completed, such serviceable stock and material as may remain will be returned to the Storekeeper,

together with a *Returned Material Card* of the form shown in Fig. 25. The Storekeeper will enter upon it the value of the material returned, credit it to the department from which it came, and sign the receipt in the lower left-hand corner. The card will then be returned to the foreman as his authority for deducting the amount from the material account in the order in question.

Follow-Up Methods for Tracing Orders in the Shop. The Sub-Production orders having been put into the departments, the first one will order the material for starting the work. For instance, the first step may be upon iron castings. Theoretically all stock and material come from the Store-Room. Therefore we might say that upon a strict construction of this general rule the castings should be furnished by the Foundry and sent to the Store-Room, from which they might be drawn upon requisitions the same as any other material. Practically this would be not only a troublesome but an expensive method, requiring a great deal of unnecessary handling and transportation. The problem is much more practically solved by considering the Foundry as one of the manufacturing departments receiving its raw material (namely, pig iron) through store-room accounts, and thus "constructively" from the store-room, while physically it is in the foundry yard. This answers the demands of a theoretical as well as a practical view of the case.

Therefore the first sub-production order will go to the iron foundry, which will make the castings and deliver them to such departments as are required to do the first work upon them, as directed upon the order. The sub-production order which this department has received, directs to what department they shall be sent when completed; and so on, until they have gone through the last department and are sent to the Finished Parts Store-Room.

This arrangement is all right as far as it goes. If every man attended strictly to his business and pushed work along as rapidly as possible, and every foreman sent his work along to the next department as soon as his department had completed its work, this plan *might* work fairly well. Unfortunately, however, these conditions seldom or never exist; and there must be ways and means devised to keep the work moving and to be able to *trace* and *locate* the work upon any order at any time when information is desired upon it or its state of progress.

To accomplish this, there is a *Transfer Office*, located as conveniently as may be for all departments, and serving as a sort of "clearing house" for all departments in transacting inter-departmental business so far as it relates to the transfer of the work in progress. By this method, departments send all their work by way of the Transfer Office, where proper records are kept of all such transfers, so that at any moment the Transfer Clerk can locate any piece of work in progress in the plant.

The operation of this method is as follows: The sub-production orders are sent to the Transfer Clerk, who fills out two *Transfer Cards*, as shown in Fig. 26, one of which he sends with the order to the first department that is to do work on the order, and the other he retains. This card provides spaces for the various departments, which are designated by numbers. Following these are spaces for entering the dates of transfers, the entries being made with a rubber stamp. After these spaces are columns for the number of pieces of work received and the number of pieces delivered.

ORDER NO.	TRANSFER CARD		
DEPT NO.	DATE OF TRANSFER	PIECES RECEIVED	PIECES DELIVERED
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
INSP			
PASSED AS CORRECT			

Fig. 26. Transfer Card.

When the first department has finished its work, the number of pieces is entered in the column headed *Pieces Delivered*, and the work and the card sent to the Transfer Office. The duplicate transfer card that was retained by the Transfer Clerk was filed in a compartment in a *Transfer Case* corresponding to the department where the work began. He stamps the date of transfer on both cards, entering the number of pieces on his own, and sends the work on its way to the next department, together with the transfer card. His own card he re-

moves from the compartment representing the first department, and places it in a compartment representing the department to which he has now sent the work.

Subsequent transfers are made in the same manner, small lots of work actually being sent to the Transfer Office, but large lots or heavy and bulky work being sent directly from one department to the next, but under the personal direction of the Transfer Clerk or his assistant.

When the parts are completed and ready for inspection, the Inspector is notified; and upon inspecting the parts previous to their being sent to the Finished Parts Store-Room, he enters the results of his work in the space at the bottom of the card that has accompanied the work in its progress through the departments.

The Transfer Clerk's *card tray* is shown in Fig. 27, and is made with compartments of sufficient dimensions to hold the number of cards expected to be on file in any one department at the same time. The cards are filed in numerical order. In a large concern the usual card-index method of guide cards is used, so as to render the work of finding the right card when wanted, easy and expeditious.

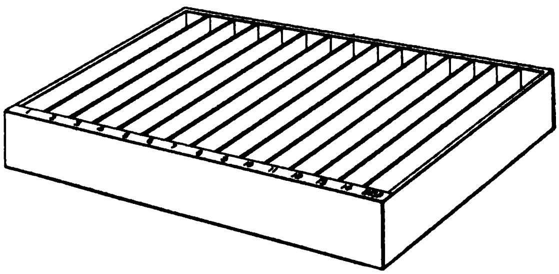


Fig. 27. Transfer Clerk's Card Tray.

Tool-Room Methods. A large number of small tools such as drills, taps, reamers, and the like, and also numerous jigs and fixtures of various kinds, are drawn daily from the Tool Room and returned there after being used. The problem of keeping track of these valuable tools, of knowing where to locate every tool that has been issued, and getting them back promptly after they have been used, is an important one.

The simplest method of doing this is by the use of small brass checks bearing the individual numbers of the men. For this purpose a *Tool Check Board*, as shown in Fig. 28, is provided. This is lined off in small square or oblong spaces, the number of spaces equaling

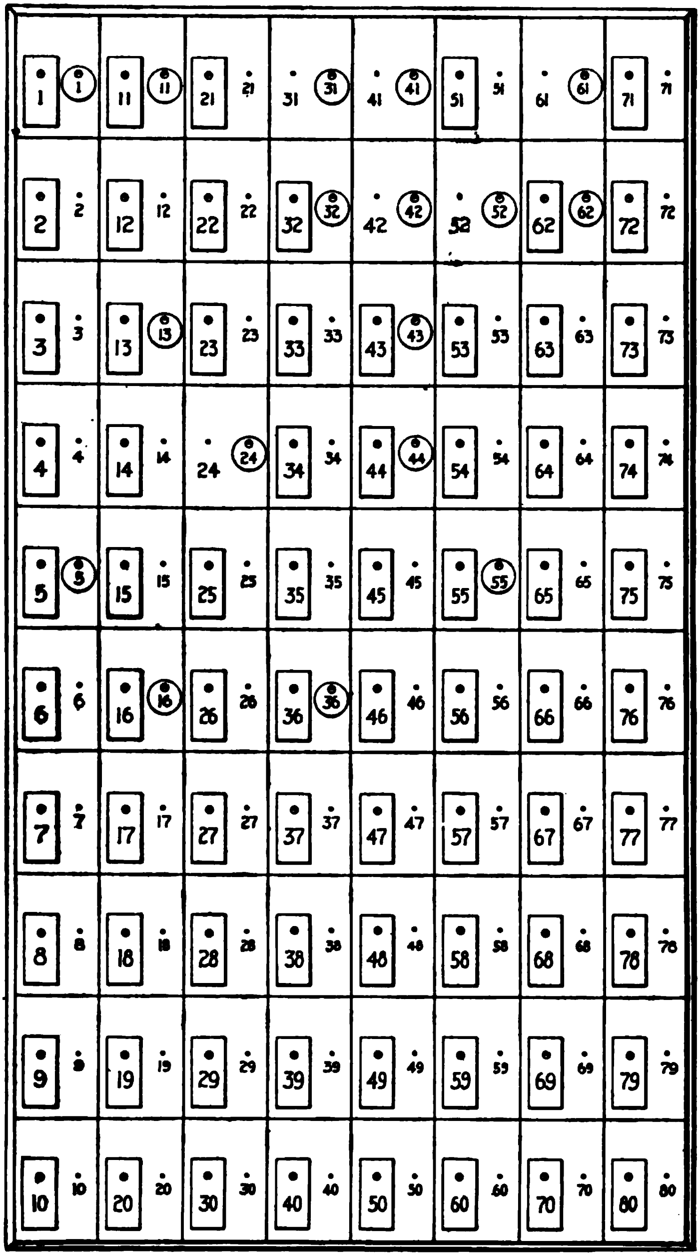


Fig. 28. Tool Check Board.

or somewhat exceeding the number of men employed in the departments served by the Tool Room. At the top of each of these spaces is the name of one of the men; and beneath the name two pins project about an inch from the face of the board. Under each pin is the man's individual number. Two forms of brass checks are used, a circular disc of $\frac{7}{8}$ inch diameter, and a rectangular one $\frac{1}{2}$ inch by $1\frac{1}{4}$ inches. Each check has a hole by which it may be hung on the pins, and each bears the individual number of the man, the checks being used in pairs of one circular and one rectangular check.

All tools are kept upon shelves, divided for individual tools or, in some similar manner; and in front of each tool is a pin similar to those on the board, upon which checks may be hung.

The operation of this method is as follows: the circular checks (there are usually twelve of them) are issued to the men of corresponding numbers. The rectangular checks are held upon the left-hand pins under the men's names. When a man goes to the Tool Room for a tool, or sends a boy for one, he presents one of his circular checks. This the Tool Keeper hangs on the right-hand pin under the man's name. He also removes one of the twelve rectangular checks, and hangs it on the pin in front of the space from which the tool was taken. If the workman sends for another tool, another circular check is added to the first one, and another rectangular check removed from the board.

It will be seen that there must always be twelve checks on the board under each name, counting both rectangular and circular ones. The absence of a tool from a shelf is accounted for by the rectangular check hung on the pin in place of it, and the number of this check shows what man has the tool. The number of circular checks on the board shows how many tools each man has in his possession.

The result of this method is that tools can be issued and taken back very rapidly; and accurate and positive records are very quickly made, without the use of a book, card, slip, or writing of any kind.

At the end of the week, *all* tools are turned in to the Tool Room, thus enabling the Tool Keeper to check them up and rectify any possible errors that may have been made during the preceding week. On Monday morning, such tools as are needed are re-issued.

BLAST FURNACE SETTLER
In this settler, the separation of the lead and slag takes place. The blast furnace is in the background

METALLURGY

INTRODUCTORY

Metal Characteristics. The metallic state in general is characterized by the presence of innumerable freely moving negatively charged and extraordinarily minute particles called *electrons*. Their presence in any substance makes it appear metallic; the remarkable facility for conducting heat and electricity, which metals possess, depends upon these same electrons; and reflecting power and opacity are correlated with their activity. Ductility, malleability, strength, and welding power also may be attributed possibly to these persistent and mobile components.

Whenever a metallic substance is dissolved in an aqueous medium, the electrons characteristically are available for the production of an electric current, while the main atomic aggregate enters the liquid, now burdened with its residue of corresponding positive electricity. The greater the tendency thus to enter solution, the more electropositive a metal is, and the more pronounced are all its other metallic properties. No two elements agree exactly in their tendency to go into solution, and, as they spread over quite a range of electrical solution potential, just as their atomic weights are spread at intervals over a considerable range, we can arrange them in an electrochemical series. Elements which fail thus to enter solution bearing a positive charge lack all metallic attributes.

Divisions of the Science. The systematic study of the science of metallurgy includes the following common divisions:

General Metallurgy. This division treats of the assembled relations, properties, and processes, as derived from the detailed study of the metallurgy of iron and steel and of the nonferrous metallurgy.

Electrometallurgy, and Hydrometallurgy. These divisions treat of certain more limited fields from the electrical and wet-chemical viewpoints, respectively. Individual metals, processes, or appliances, when important enough, are commonly treated as separate subjects; such are: the *metallurgy of steel, foundry practice, and electric furnaces.*

Metallography. This is a strong young science which treats of the structure of the metals; it especially studies all the internal physical and chemical properties of the metallic state; it investigates metallic compounds, liquid and solid metallic solutions, solidifications, transitions, and crystal form.

The art of metallurgy consists in extracting the metals from their ores and in purifying and preparing them for consumption in the manufacturing industries and trades. Of course quite a bit of ore preparation often is included in metallurgy; likewise much manufacturing may be tagged on to strictly metallurgical operations, as when a steel plant sends its product out in the shape of railroad spikes.

Extent of Metallurgical Study. Metallurgy cannot confine itself to a study of the preparation and properties of the nineteen common metals—sodium, magnesium, aluminum, iron, nickel, copper, zinc, palladium, silver, cadmium, tin, antimony, tungsten, iridium, platinum, gold, mercury, lead, and bismuth—and of the seven common alloying elements—silicon, titanium, vanadium, chromium, manganese, cobalt, and molybdenum—but finds itself in the most intimate contact with, and use of, many of the other phases of human activity.

Relation to Other Subjects. Mining engineering equally is concerned with the recovery of placer gold; the miner must dig for the metallurgist, just as the miner can afford to recover only those ores which the metallurgist can use. Ore dressing is claimed by mining engineering and by metallurgy, and is made independent only by a strong exponent. Chemical engineering in one school may embrace metallurgy, in another it may be separated fully. Electrical engineering finds a fertile field in metallurgical plants; civil and mechanical engineers often are at the same problem with the metallurgist, who as far as possible, must master their accomplishments.

The metallurgist often must do work in the strictest and purest fields of physics, chemistry, and mathematics; and their progress is the foundation for all his best efforts. Not seldom do political economy, finance, transportation, and hygiene modify his operations profoundly, but the metallurgist needs now and then to adjust his operations to the whims and traditions of those who work with him and those who buy his product.

Universal Employment of Metals. The importance of metallurgy is evident when we consider that the essential features of our

modern civilization are woven on a support of iron and steel; remove this metallic skeleton or imagine it lost, and our personal sphere utterly collapses.

Hardly an effort of labor can be performed without the use of a metallic object, be it the work of the laborer in the ditch with his iron-carbon alloy, or the President signing a state document with a platinum-iridium pointed gold pen. We live in homes well equipped and decorated with metallic objects; we carry metallic objects for use and show—the same as fabrics—and consider a gem perfect only in the most costly setting.

Relative Production of Metals. *General.* The transportation of ores is the greatest tonnage commodity of the railroads. The strictly metallurgical industries rank well to the front—as far as the money value of our yearly products is concerned, over a billion dollars' worth of metal in the unfabricated state being produced each year. The stock of accumulated metals is one of the chief treasures and resources of any people.

Gold. Gold is the standard of value and the basis of finance. While our national wealth, both private and public, is increasing enormously year by year, our gold production is not quite a dollar's worth per person at the present time. For over 100,000,000 people, the United States produced slightly under $99,000,000 in gold during 1915. As a matter of fact, the world's production of gold now is on the decline. Trade exigencies swing the transfer of gold violently from nation to nation. One year we export more than we mine; another, the whole world's production of some $450,000,000 is shipped to us. Financial panics are largely scrambles for gold. Gold has slight intrinsic value and any rational substitution of a new material for it or of a fiat basis for values, immediately would have the most profound and sweeping reaction, not only on gold mining, but on the entire number of industries connected with the production of silver, copper, and lead.

Other Metals. This year there is produced, per capita, in the United States over 800 pounds of iron, 13 pounds of copper, 10 pounds of lead, 8 pounds of zinc, and 1½ pounds of aluminum. We are, by far, the leading nation in the production and use of the metals. There are strong indications that more populous nations than our own gradually will find need for the metals, as we do. There is,

therefore, little likelihood of any very long continued slump in either metal production or metal values.

Future Progress. Matters of the greatest import are the progress continually being made in the production of purer and purer metals in huge quantities, and the striking success in making alloys of new properties. There is no reason to think otherwise than that this phase of metallurgy is still in its beginning; a conception promising to everybody.

Literature on Metallurgy. The bulletins of professional, scientific, and government bodies afford an abundance of first-class information on all current metallurgical subjects. The trade journals get some new articles, but mainly spread the more technical information of the first group. Perfunctory treatises demand such attainment by their authors that, if they are at all broad in scope, they fail lamentably. Treatises on special subjects, on the contrary, are usually very much worth while. In general, both the science and the industry are presented exceptionally well to the public.

References. The information contained in the following treatises and periodicals is of the first quality.

General Metallurgy:

"Introduction to Metallurgy", Roberts. Austen (1910)
"Principles of Metallurgy", Fulton (1910)
"Metallurgical Calculations", Richards (1907)
"Physical Metallurgy". Rosenhain (1914)
"General Metallurgy", Hofman (1913)
"Métallographie", Guertler (1912-1913)
"Revue de Métallurgie" (monthly), Paris
"Metallurgical and Chemical Engineering" (semimonthly), New York
"Metall und Erz" (monthly), Halle
"Bulletin, American Institute of Mining Engineers" (monthly), New York
"The Mineral Industry" (yearly), New York

Iron and Steel:

"Cast Iron in the Light of Recent Research", W. H. Hatfield (1912)
"The Metallurgy of Steel", Harbord and Hall (1911)
"Liquid Steel", D. Carnegie (1913)

"Metallography and Heat Treatment of Iron and Steel", Sauveur (1916)

"Metallography of Steel and Cast Iron", Howe (1916)

"Cementation of Iron and Steel", Giolitti (1914)

"Stahl and Eisen" (weekly), Duesseldorf

"The Iron Age" (weekly), New York

"The Iron Trade Review" (weekly), Cleveland

Copper:

"Metallurgy of Copper", Hofman (1914)

"Practice of Copper Smelting", Peters (1911)

"Hydrometallurgy of Copper", Greenawalt (1912)

Lead:

"The Metallurgy of Lead", Collins (1910)

Zinc:

"Zink und Cadmium", Liebig (1913)

GENERAL METALLURGY

PROPERTIES OF METALS

Reducibility. The useful metals cover almost the entire range of the metallic elements in the electrochemical series. This generalization of the chemist is the same as the metallurgist's statement that the metals have all degrees of reducibility. The sequel illustrates abundantly what we mean. Sodium stands near the very extreme of the electropositive end of the list, with an affinity for oxygen and chlorine so powerful that decomposition and isolation are effected only by the most energetic chemical or electrochemical means. At the other end of the series are gold, iridium, and platinum, with solution pressures so faint that they naturally retain the metallic state and can be forced to combine with only a limited number of the most electronegative nonmetallic elements. Simply heating any of their compounds throws out these latter metals ready to melt for the market.

Metallurgical Series. The metals, in general, are won by heating and reducing under proper chemical influences, but there are important exceptions. The arrangement in metallurgical series, Table I, indicates the degree of reducibility of the various metals.

TABLE I

Comparative Reducibility

Degree of Facility	Means	Metal
(1)	By heating compounds—if originally metallic, merely fuse	Gold Platinum Palladium Iridium
(2)	From oxide compounds, easily, by metallic iron or by hot carbon monoxide	Lead Cadmium Tin Bismuth Copper Mercury Silver Antimony
(3)	Only by carbon at 1000° C., in absence of carbon dioxide	Zinc Iron Nickel Cobalt
(4)	With nothing less than metallic aluminum at very high temperature	Chromium Manganese Titanium Vanadium Molybdenum
(5)	Only by electricity, in absence of free or unavailable electronegative elements	Sodium Magnesium Aluminum

Crystallization. One of the superlative properties of all metals is crystallization, and on the exact condition of the crystals in any metal often hangs every degree of usefulness. An intimate glimpse into the complex nature of an ordinary steel is given in Fig. 1, in which the sharply separated crystals with boundary cement and internal granules are as plain as the stones in a building. The same applies to a sample of ordinary copper as seen in Fig. 2.

All metals have been found to crystallize on solidifying from the molten state; even after the severest strains and deformations, the crystal nature persists. Deformed crystals give birth to a new growth of crystals, if the temperature will allow the readjustment. Maximum ductility usually accompanies well-grown crystals; maximum strength accompanies the first incipient growths of a newly disseminated structure from some previous formation, probably through surface forces. Brittleness and weakness commonly are developed through the coalescence between large crystals of the

material by some substances of friable nature; impurities and overheating thus form an aggravating combination.

An amorphous state is a plausible assumption to account for the cement between grains, the débris along slipped cleavage planes and colloidal metal solidified by pressure instead of fusion. The study of this condition is now assuming notice and promises brilliant results for science and industry.

Hardness. The hardness of a metal often is of prime importance. The ideas of scratching, cutting, indentation, transient impact, and

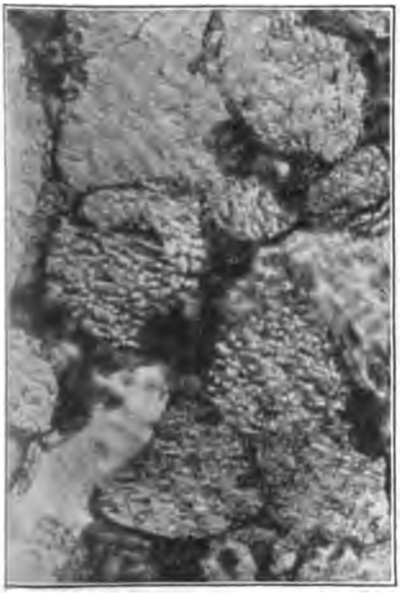


Fig. 1. Very Low Carbon Steel. Specimen Magnified 700 Diameters; Shows the Coarse Grain and Secondary Granulations

Fig. 2. Rolled and Annealed Copper. Specimen Magnified 1000 Diameters; Shows Coarse Grain and Fibers of the Grain

permanent deformation all are conveyed in the term *hardness*. Various measuring instruments have been devised; of these the Brinell ball-indentation machine and the Shore scleroscope are the most common.

Brinell Hardness Tester. In using the Brinell machine which is shown in Fig. 3, the steel ball, 10 mm. in diameter, is pressed into the metal with a force of 3000 kg. The size of the indentation after applying the pressure for 15 seconds measures the hardness.

Scleroscope. As illustrated in Fig. 4, this instrument, operated pneumatically, lets fall a weight whose diamond point cuts the

surface of the metal, yet is blunt enough to be quickly resisted by the spreading metal; the upward rebound is measured on a scale whose 100 mark is exactly equaled on a hard standard steel.

Strength. *Factors.* This property of resistance to pulling apart or bending is modified wonderfully both by the chemical nature of the particles of a metal, by their size, and by the way in which they are arranged. The purest and softest iron which has a

Fig. 3. Brinell Hardness Tester

tensile strength of some 40,000 pounds per square inch, can be brought, by alloying and working and right heating, up to a strength of 400,000 pounds per square inch in small sections. The proper heat treatment and working often can increase a metal's strength 100 per cent over an original cast condition.

The strengths of all metals vary so with composition and treatment that any specified strength has little meaning unless accompanied by the facts of composition, and of heat and mechanical treatments.

Fatigue. All metals are susceptible to a gradual weakening by progressive internal rupture, when subjected to enough alternating strains to affect—although to not exceed—the elastic limit of the metal. This is called *fatigue;* many materials yield to it after a few thousand trials; those which require millions of alternations to rupture are said to be very *resistant to fatigue.*

Fig. 4. Shore Scleroscope Testing Hardness of Cartridge Case
Courtesy of Shore Instrument and Manufacturing Company,
New York City

Plasticity. Plasticity, or the flow of metals under pressure, is by no means a general or uniform property of the metals. As already intimated, there are all degrees of malleability in the cold, the degree evidently being associated closely with the perfection of electrical and heat conductivities (see Table II). What may be considered malleability at one temperature is the slipping of the atoms along crystal cleavage planes; at a higher temperature, a similar deforma-

TABLE II

Physical Constants

Metal	Melting Point (Degree centigrade)	Coefficient of Linear Expansion (Per degree between 0°—100°)	Density (Water = 1.0)	Specific Heat at 15° (Water = 1.0)	Electrical Conductivity at 0° (Hg. = 10,650)	Constant of Heat Conductivity (Calories per second through 1 centimeter cube; 1 degree difference)
Sodium	97.5	.000072	.97	.293	211,000	...
Magnesium	651	.000027	1.74	.246	230,000	.38
Aluminum	658.7	.000023	.266	.167	324,000	.35
Iron	1530	.000012	7.86	.116	131,000	.17
Nickel	1452	.000013	8.80	.109	144,200	.14
Copper	1083	.000017	8.94	.092	620,000	.72
Zinc	419.4	.000029	7.15	.093	186,000	.26
Palladium	1549	.000012	11.40	.059	....	.17
Silver	960.5	.000019	10.56	.055	679,000	1.096
Cadmium	320.9	.000030	8.60	.054	144,100	.21
Tin	231.9	.000023	7.30	.055	76,600	.14
Antimony	630	.000017	6.71	.048	27,100	.04
Tungsten	3175	.000004	19.70	.036	......	.35
Iridium	2300	.000007	22.42	.030	......	...
Platinum	1755	.000009	21.50	.032	63,500	.17
Gold	1063	.000014	19.25	.030	461,000	.70
Mercury	−38.7	.000181	13.59	.033	10,630	.02
Lead	327.4	.000029	11.34	.030	50,400	.08
Cismuth	271	.000013	9.82	.030	9,260	.02

tion may be the flow of an extremely viscid and tenacious solid solution.

Conditions. Although this malleability is a cardinal property of the most useful metals, each metal or alloy requires specific conditions for making use of the property, if, indeed, it can be used at all. For cold working, a metal frequently is annealed, lest crystal ruptures be developed exactly as in an overdone fatigue test (rolling gold and silver). Compounds present dare not be overlooked (cementite present in tool steel in the cold is in solution at red heat). Temperatures and chemical actions must be within bounds (steel "burned" has been heated until actually deeply oxidized), while, finally, at the temperature of optimum workability, extreme care must be taken not to damage physically the weakened but still cohesive metal (in welding steel, slag and scale often are forced into the main body of the metal). In fact, the conditions under which each separate metal shall be worked, must be most carefully studied.

TABLE III

Chemical Source of the Metals

Native	Oxides	Sulphides	Carbonates	Silicates	Chlorides
Copper	Aluminum	Nickel	Magnesium	Copper	Sodium
Palladium	Silicon	Cobalt	Iron	Zinc	Magnesium
Silver	Chromium	Copper	Copper		Silver
Gold	Manganese	Zinc	Zinc		
Mercury	Iron	Silver	Lead		
Iridium	Vanadium	Molybdenum			
Platinum	Titanium	Cadmium			
Bismuth	Copper	Antimony			
	Tin	Bismuth			

ORES

Economic Value. An *ore* is a metal-bearing substance from which a metal, alloy, or metallic compound can be extracted at a profit. Ores are the aggregates containing the minerals of economic value. *Gangue* is the portion of the ore not desired or which must be wasted in the recovery of the metal. Gangue removed by a fusion is called *slag*. The gangue of one century or decade is not infrequently the ore of the succeeding period.

The economically valuable minerals are chiefly native metals, oxides, sulphides, carbonates, silicates, or chlorides, as grouped in Table III.

Distinctions in Values. It is vitally important to distinguish an ore deposit from an occurrence of a few handsome mineral specimens. The universally distributed and often pure and massive sulphides of iron are never directly ores of iron; the stupendous amounts of fairly pure silicate of aluminum are not ores of aluminum; dolomite is not an ore of magnesium; sea water, although it may contain more gold than does a gravel which is actually worked, yet is not an ore of gold; strictly speaking, we have no ores of cadmium, palladium, or iridium, for these metals are recovered only as by-products in the working-up of other metals.

Again, we must keep in mind that, although the metallic content of a rock figured into dollars at market metal prices may amount to $50 or $75 a ton, yet that rock may be without value, either if the metals are inseparable, or some inconspicuous deleterious element is present, or if the cost of treatment is greater than the recovered values.

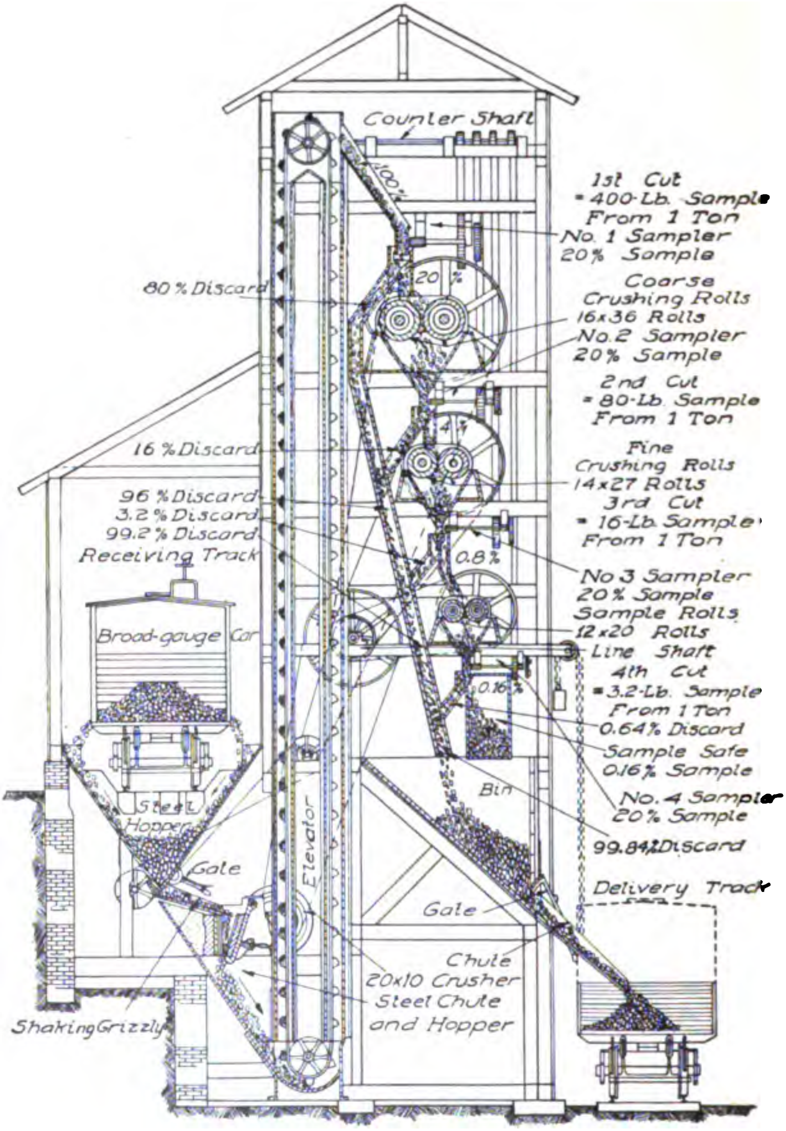


Fig. 5. Diagram of Ore-Sampling Mill
Courtesy of American Institute of Mining Engineers

Sampling

Importance. All modern metallurgical operations are under chemical control. Before a chemical analysis can be made, the material must be sampled properly. Obviously, then, accurate sampling is equally important with correct analysis.

The sampling of materials is found in all stages of metallurgical operations, from raw material to finished product. It is essential from the buying and selling viewpoint, for economy and recovery, for purity and composition of final product.

Methods. Sampling may be accomplished in the mine. There it will be done by sinking shafts, by churn drilling, by core drilling,

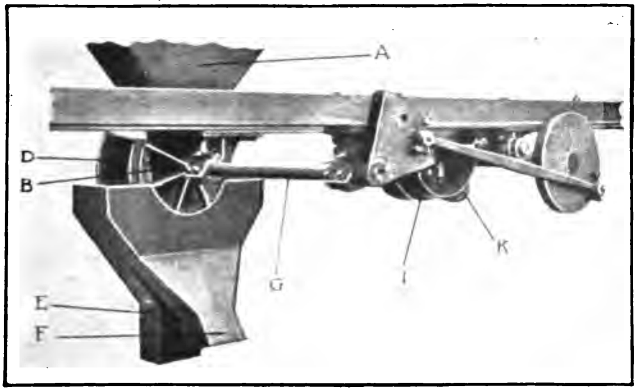


Fig. 6. Brunton Sample Cutter
Courtesy of American Institute of Mining Engineers

by twist drilling, by exposure cuttings, by grab sampling, or by selecting certain units such as a small car-full or an entire load in a railroad car.

Sampling Mill. Many mines and metallurgical plants maintain special mills in which systematic sampling is effected by scientific divisions after finer and finer crushings. If the material is already fine, a portion will be selected by coning and quartering, by fifth-shovel sampling, or by the use of stationary cutters. If the material is coarse and needs to be kept so, the sampling will be by selecting portions from a falling stream, crushing, and again cutting the stream. In this way, after four to six selections, a small sample is obtained which accurately represents the entire lot of many tons.

Fig. 5 gives, in outline, the operation of such a mill. The student should follow in detail the course of the material from the in-coming to the out-loading car. Note how many times the ore stream is divided before the sample finally is received in the safe. Observe the methods for reducing the size of the chunks.

The actual sampling cutter in this mill is seen in Fig. 6 just as it is placed in the mill. The single collecting hopper *A* guides the ore stream through the narrower channel *B* to above the fractionating oscillator *D*, which separates it partly into the discard spout *E*, and partly into the sample spout *F*. *G* is the oscillating shaft; *K* an eccentric gear; *I* a gear shift.

Fig. 7. Braun Laboratory Sampler

Laboratory Sampler. Fig. 7 illustrates a simple mechanism to effect the cutting-out of a sample on a much smaller scale. It is seen that the feeding spout has mechanical shaking to work the material in uniformly. The discard is cleared away on the belt conveyor, while the selected smaller sample is caught in the bucket. Inside the main chamber is a revolving segmented cutter which throws a large portion of the ore stream out through the large discharge, and throws a smaller but impartially selected portion into the funnel over the bucket.

Crushing and Cutting. In the crush-and-cut method of mill sampling three very distinct ratios have to be maintained properly. These are: (1) size of largest particle to total weight of lot, with an ample factor to allow for increasing in homogeneity; (2) number of selections to uniformity of the lot—the more dissimilar, the more cuts are required; (3) size of opening to size of largest particle—which properly may be about 10.

Fig. 8 pictures one of the most convenient laboratory cutters yet designed for fine dry materials. When material is poured into the

hopper with a shaking motion, it will receive numerous cuts and be divided into two portions. The cutting then can be repeated until the sample selected is of small enough size.

Coning and Quartering. Where mechanical methods are not available, excellent results can be obtained by coning and quartering. This venerable method is discredited abundantly but is wonderfully serviceable when necessity demands.

In Fig. 9 is shown this practice in a large Mexican smeltery. One by one the piles will be spread out, until they are not over 10 or 12 inches thick; with a marker the lot then will be quartered, and

Fig. 8. McCann Sampler for Fine Dry Materials
Courtesy of Mine and Smelter Supply Company, New York City

men will shovel away opposite quarters as discard and again cone up the two remaining quarters. This will be continued, with much breaking of the lumps, until the sample is small enough to go to the laboratory for grinding and for further division on a cutter like that of Fig. 8. In the illustration the Mexicans in the background are at work shoveling the discarded quarters into the wheelbarrow. Such a sampling floor is kept scrupulously clean; the dust is kept down with sprinkling.

Molten Dipping. Well-mixed molten materials are sampled accurately by dipping out small units, each approximately of the right size for the chemist or assayer without further division.

Punching. Punch sampling of cakes, slabs, and ingots is much used. We have learned that all metals crystallize on cooling to

assume the solid state; this means that the mother magma will be enriched with impurities and solidify last; in other words, all ingots show segregation. Sometimes the irregularities can be kept small; often they are surprisingly large.

Testing Finished Product. Sampling a finished product by selecting and testing a few units is practiced commonly. Obviously

Fig. 9. Sampling Floor of a Mexican Smeltery

this presupposes a uniform product; such sampling has the same inconclusiveness as there is in the case of grab sampling.

PRETREATMENT OF ORES

Metallurgical Processes in Ore Dressing. Besides the numerous and highly technical methods of ore concentration as practiced in the art of ore dressing, there are a few processes distinctively metallurgical which must be considered.

Drying. Not infrequently materials must be dried to avoid freight charges, or in order to supply perfectly dry material for further treatment (as preparatory to electrostatic separation), or preparatory to roasting. Mechanical dryers have been brought to high perfection and can do the work efficiently. Such a revolving tumbling and heating cylinder is seen in Fig. 10. Both the fire box and the flue are at the far end, for in this particular type the gases

of combustion travel twice the length of the cylinder before discharging; it has internal partitions for this purpose. The feed hopper is at the far end, and the material discharges from the near end into the rolls.

Calcining. Calcining in kilns or furnaces may be practiced to get rid of moisture and carbon dioxide preparatory to the shipment of ores, or to put the ores in the best form for reduction. Several types of furnace are used.

Roasting. Roasting may be performed to get rid of sulphur, to change from sulphide to oxide, to change to sulphate, to rid of

Fig. 10. Pair of Ore Dryers Feeding into Crushing Rolls
Courtesy of Ruggles-Coles Company, New York City

arsenic, antimony, or tellurium, with salt to chloridize, or simply to volatilize. The most conservative method is on a flat-hearthed reverberatory; many more recent and improved types are in use. Fig. 11 shows the hand-rabbled reverberatory as used in many countries and for all of the purposes just mentioned. The charge will be pushed slowly the entire length of the furnace, toward the fire box, and finally raked out as we see the man doing in the picture.

Sintering. Sintering is becoming more common with iron ores as preparatory to blast-furnace reduction; if carried out in a revolv-

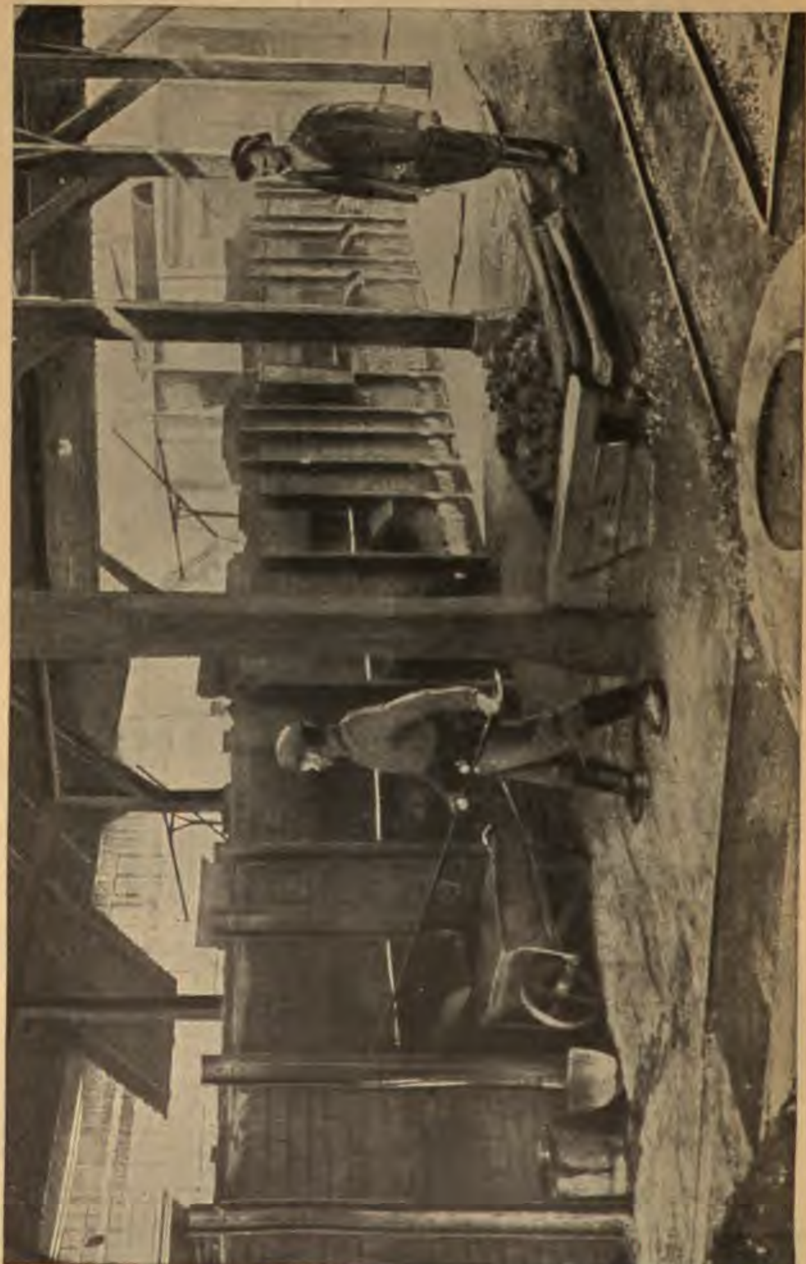


Fig. 11. Hand-Rabbled Reverberatory Roaster
Courtesy of Royal Austrian Commission

ing cylinder it likely will be termed *nodulizing*. Fig. 12 shows just such a nodulizing cylinder. The ore is fed in through the opening *A*; *B* is the cylindrical steel drum revolving on rollers *C*; the dis-

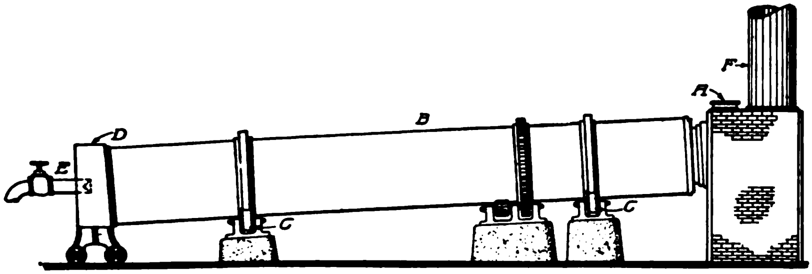


Fig. 12. Iron-Ore Nodulizing Kiln. *A*—Feed; *B*—Rotating Furnace; *C*—Rollers; *D*—Discharge Hood; *E*—Gas Burner; *F*—Stack

charge hood is at *D*; the gas burner is at *E*; and the gases exhaust through the stack *F*.

Roast-Sintering. This is now the standard preparatory method for sulphide ores before smelting in the lead blast furnace. It leaves the material both desulphurized and chunky. When iron ores are

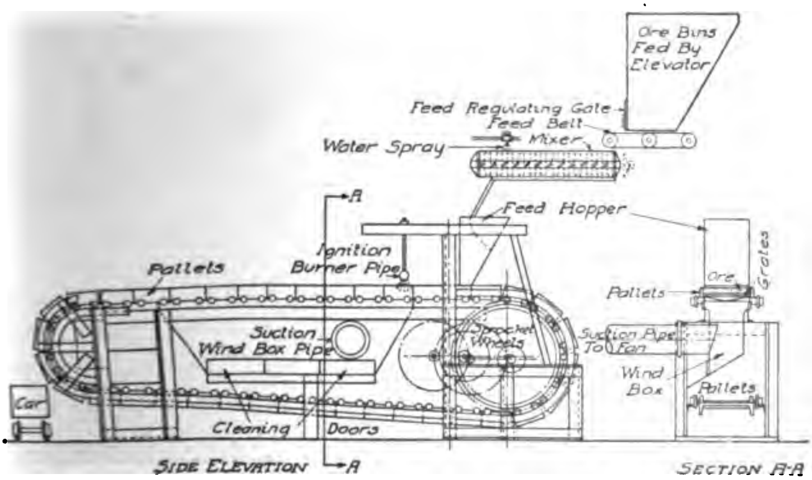


Fig. 13. Continuous Roast-Sintering Machine
Courtesy of American Institute of Mining Engineers

thus treated, the sulphur is lowered and the material is agglomerated as well. The principle of the continuous machine with down draft is seen sketched in Fig. 13. The charge feeds down through the

mixer and the moistener upon the continuous-grate system just in front of the ignition burner. When ignited, the glowing cake is carried across and over the suction box as the combustion extends through the mass, so as to complete the work before the cake breaks off, finished, into the waiting car.

Briquetting. Fig. 14 shows a pug mill in the background, within which two heavy rollers mix and grind the charge and finally press it through holes in a revolving thick steel disc so as to form the round cakes which are seen piled beside the conveyor extending forward from the pug mill. These particular cakes

Fig. 14. Pile of Briquettes with Conveyor Coming from Briquetting Machine

have been ground up with milk of lime as binder. This process is common for making fine and powdery materials into cakes suitable for blast-furnace reduction. Because of the rapid development of roast-sintering as a preparatory process, briquettes are fast losing in importance.

Chemical Solution or Fusion. The method of chemical solution or fusion is sometimes found necessary in cases where other and cheaper methods are not suitable. The process requires no unusual apparatus. Pure alumina is prepared thus from bauxite; by this process tungsten can be separated from the iron and the lime with which it occurs in nature.

FURNACES

Classification. A bewildering variety of furnaces is in use in the metallurgical industries. Almost every metal, as well as each process for the same metal, has its own particular furnace. Only in the broadest sense can furnaces be classified. They cover a great range of working temperatures, of capacities from ounces to thousands of tons, and of chemical influences from the strongest oxidizing to the most powerfully reducing. Classification according to fuel and mode of receiving the heat is as follows:

I. *Fuel Furnaces (either gas-, oil-, wood-, coal-, or coke-fired):*
- (A) Direct Contact with Solid Fuel
  - (1) Hearths
    - (a) Open hearths or crucibles (blowpipe melting)
    - (b) Forges (the ancient Catlan forge for making iron)
    - (c) Lead-ore hearth (for melting rich galenas)
  - (2) Shaft furnaces: Blast furnaces. Used with solid fuel for reducing ores of iron, copper, lead, and tin
- (B) Charge Separated from Fuel (either solid, liquid, or gas fuel); radiation heating mainly
  - (1) Reverberatory furnaces. This type of furnace is used for more purposes and on more metals than any other sort of furnace; variations are equally numerous
- (C) Charge Inclosed; heated by conduction through walls
  - (1) Crucible furnaces (for melting steel, etc.)
  - (2) Retort furnaces (for smelting zinc, etc.)
  - (3) Tube furnaces (for liquating bismuth)
  - (4) Muffle furnaces (for roasting sulphides and the rich sulphur-dioxide gas used to make sulphuric acid)

II. *Charge Containing Own Fuel:*
- (A) Converters (for blowing matte to blister copper, and iron to steel)
- (B) Aluminothermic Crucibles; in which oxides are reduced to metals with metallic aluminum

III. *Electric Furnaces:*
- (A) Pure Arc Heating (Stassano steel furnace)
- (B) Induction (Roechling-Rodenhauser type)
- (C) Resistance (aluminum furnaces)
- (D) Arc and Resistance, Combined (Heroult and Girod).

Variation of Types. Electric furnaces, converters, crucible furnaces, and reverberatories are made tilting as well as stationary. Almost any combination of the above furnaces is possible and many such are in use.

Insulating Materials and Refractory Linings. What substance shall restrain and hold the reacting chemicals in the multitude of

Fig. 15. Welded Water Jackets for a 48 by 192 Inch Copper Furnace
Courtesy of Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin

furnaces just described? What materials will keep the heat in? What materials will conduct the heat away fast enough? What will withstand very high temperatures? What will resist excess of acid influence? What will resist hot and powerful bases? No subject is more important to the metallurgist than refractories, for

possibly it is not only high temperatures and chemical action but *changing* temperature which must be withstood.

(1) *Chilled Substance Itself.* This is a very neat and absolute solution when it can be applied. It is used most in the electro-thermic furnaces but borders on our next refractory, water-cooled jackets.

(2) *Water-Cooled Metal Jackets.* Here a very thin layer of the charge will be frozen on the metal which is cooled by an abundant supply of water. All blast furnaces now are cooled with water blocks or large flat or annular jackets about the fusion zone. Fig. 15 shows a large rectangular jacket assembled in the shop. Hand holes for cleaning out are at the very base; tuyère thimbles are in each jacket just below the bosh; about the center of the bosh are the water inlets; the overflow is at the very tip top of each jacket. The jackets are firmly bolted together to keep from being squeezed apart by the charge.

(3) *Fireclay.* Hydrous aluminum silicate, as found abundantly in nature, not only lends itself well to molding and baking into strong shapes, but admirably resists temperatures up to some 1500° C., and is neither decidedly acid nor basic in its character. This is a very widely used refractory.

(4) *Silica and Siliceous Materials.* This refractory also is easily worked and fritted into suitable shapes. It is used much for acid hearth linings, for roofs, and for side walls.

(5) *Carbon and Graphite.* The crucible of the iron blast furnace is essentially a graphite-lined receptacle, and is automatically so. This refractory will stand any obtainable temperature, but cannot be used in the presence of air or reducible oxides.

(6) *Magnesium Oxide.* Magnesium oxide, which has been carefully calcined and shrunk, is a widely used brick and hearth lining. It is for use with the bath basic or metallic. Particular care must be taken that steam does not get a chance at any time to slack and ruin this material.

(7) *Bauxite* (Al_2O_3).

(8) *Carborundum* (CSi).

(9) *Chromite* ($FeCr_2O_4$).

(10) *Brasque* (mixture of sand, fireclay, and coke).

(11) *Zirconia* (ZrO_2).

(12) *Boron Nitride* (BN).

Brasque is an ancient refractory, now little used for more than backing some primary lining. The others of the last six are all promising materials which doubtless will receive greater application when they become better known and more available.

METALLURGY OF IRON AND STEEL

ORES OF IRON

Supply and Consumption. Although the world is using up iron ores at the rate of over 150,000,000 tons a year, the supply keeps increasing from new discoveries and better preparation of lean ores. The principal countries of the globe are well supplied, each with enough in sight to last many years. The United States is especially well provided, not only within its own borders but in adjacent countries. We now have probably 10,000,000,000 tons which we may call the reserve, and our present yearly consumption of some 50,000,000 tons can be increased considerably without fear of exhaustion.

Mineral Sources. The minerals which constitute the main ores of iron are shown in Table IV. Magnetite and siderite are minerals forming only minor ore deposits as at present available. Hematite is our present chief mineral. The deposits of the hydrous oxides are especially large and have more promise for future usefulness.

Methods of Preparation. In preparing iron ores for the blast furnace, we use drying, washing, and magnetic concentration, calcining, nodulizing, sintering, and briquetting.

Fig. 16 indicates with what seriousness the large companies are beginning to work lower-grade deposits. This particular plant is for washing some 20,000 tons of iron ore each day. It is a carefully designed and costly plant. The fines which are blown out of the

TABLE IV

Principal Iron Ores

Mineral	Composition	Iron, Percentage
Magnetite	Fe_3O_4	72.4
Hematite	Fe_2O_3	70.0
Limonite	$2Fe_2O_3 \cdot 3H_2O$	60.0
Goethite	$Fe_2O_3 \cdot H_2O$	63.0
Turgite	$2Fe_2O_3 \cdot H_2O$	66.3
Siderite	$FeCO_3$	48.3

furnace and collected in dust catchers and washers are just as good as new ore, if they are agglomerated; the working up of these fines with fresh fine ore is a rapidly developing phase of the smelting.

BLAST FURNACE

Importance. The blast furnace is the real heart of the iron and steel industry; it is the most important device which mankind yet has developed. The continued operation of the furnaces is related to our daily life in a similar sense as is the daily rising of the sun—

Fig. 16. Iron-Ore Washing Plant to Treat Twenty Thousand Tons a Day
This plant is located at Coleraine, Minnesota.

we could get along without either for a while, but soon our whole condition of existence would change.

Plan of Operation. The blast furnace for smelting iron ores is one of our largest machines and also one of the most complicated. At the top is charged in the iron ore, the limestone to flux the gangue, and the coke as the fuel. Near the top exit continuously the gases from the combustions and reactions, as well as the flue dust. The gas has considerable fuel value and is used partly to reheat the blast and partly to drive the engines for furnishing the blast, while a further portion is left over to use as desired in the plant. Through the tuyères near the bottom of the furnace a great quantity of hot air is

blown in to burn the coke and to maintain the smelting temperature of some 1600° C. Iron is tapped out every six hours from the bottom of the furnace, and slag is tapped more frequently from the cinder notch a little higher up but still below the tuyères. As the charge settles through the furnace the iron ore is reduced to

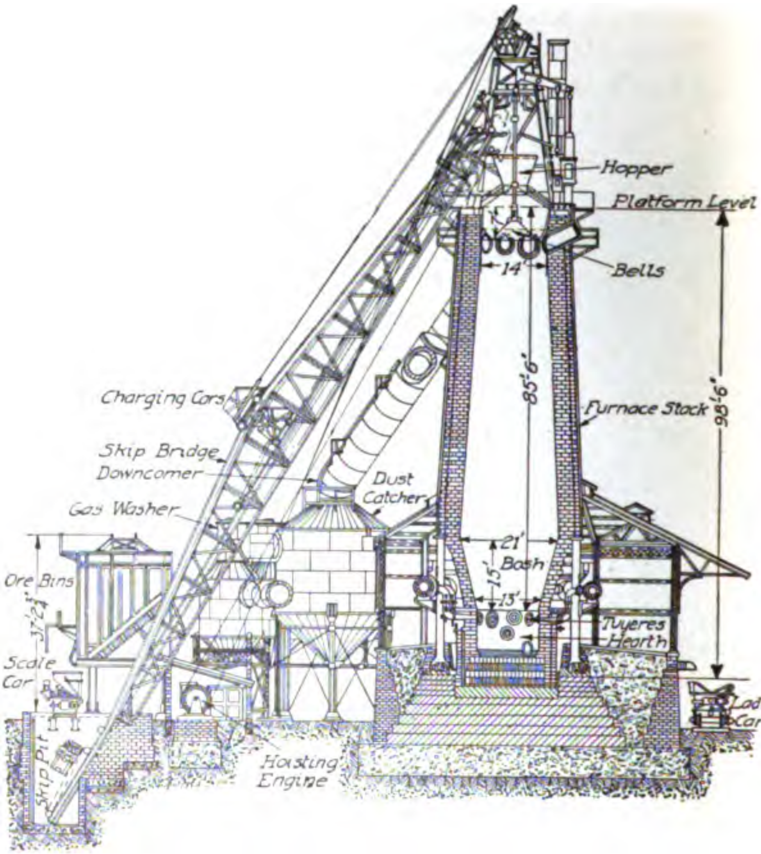


Fig. 17. Vertical Section of Iron Blast Furnace
Courtesy of "Engineering and Mining Journal"

metallic iron. The limestone is calcined to lime; when the charge has settled far enough, the lime and silica of the gangue combine to make the slag, while the iron saturates with all of the available carbon, silicon, manganese, and phosphorus, and at last, wholly molten, trickles into the crucible to await casting time.

Elements of Construction. To accomplish the reduction fully and to maintain the high and constant heat necessary, a large and immensely strong furnace is required. The base is a massive foundation; the crucible is water-cooled and is bound in with thick steel bands; the tuyère nozzles are clamped solidly; the boshed fusion

Fig. 18. Casting Iron at a Modern Furnace

zone is of the best firebrick held with heavy thick steel bands and is cooled thoroughly with bronze water blocks; the shaft is a massive steel shell lined with first-quality firebrick.

Fig. 17 is a section through a large iron blast furnace. This cut admits of a close inspection of the lines of the furnace: the cru-

cible, tuyères, and boshed zone each are indicated clearly. Above the boshed zone the main upright truncated cone of the shaft extends upward; note how this shaft is supported on special columns, and see the thickness of the walls. Figure out how the bell mechanism at the top allows the charge to get inside the furnace without letting the gases escape. The inside dimensions should be copied and the shape should be redrawn on a larger scale. Follow the iron ore from the ore bin, and explain which part comes out through the dust catcher, which part through the iron tap, and which part through the cinder notch.

Actual Operation. In the halftone from the photograph of the furnace, Fig. 18, we have a fair view of what the inside of the casting room looks like when the pig iron is running from the furnace. The hot metal is pouring out in a thick stream and runs through the iron and sand channels into the ladle at one side and lower than the floor of the casting room. Men are on hand to keep the flow of metal clear of obstructions. The big bustle pipe around the bosh is much in evidence, as are also the pipes connecting to the tuyères which are seen inserted between the steel bands around the furnace. Just over the runway, which is immediately above the bustle pipe, can be seen the many overflows of the cooling water which has circulated throughout all the lower section of the furnace inside the cooling blocks; each of these overflows is in plain sight from the floor. A big annular drain box collects all the water, which then flows away through the big pipe leading down over the men at the right.

The usual furnace of today makes about 500 tons of pig iron a day. Each ton of iron produced requires some 2 tons of ore and a ton of coke in the charge, besides the necessary limestone, while for this same tonnage of iron some 4 tons of hot air must be driven through the tuyères under a pressure of from 15 to 30 pounds per square inch. At the top a double bell-valve arrangement is necessary to drop in the frequently arriving skips of charge without letting out the gases which are carefully conserved and, after leading down and through the dust catcher, are conducted to the other parts of the plant.

SECONDARY ELEMENTS OF FURNACE PLANT

While the blast furnace is the most vital part of any iron or steel plant, there are accessories absolutely essential for its operations.

Raw Material. Enormous stocks of ore, limestone, and coke must be ever ready for charging into the insatiable stack; this means great piles of ore and stone, and plenty of coke either being made or continuously coming into the plant. Reliable and powerful bridges, cranes, grab buckets, transfer and scale cars, etc., must be in place to span the stock piles and to load the skips.

Stoves. Huge stoves are built in line near the furnace to heat the blast; four stoves, each nearly as big around and as tall as the furnace itself, are commonly supplied to heat the blast. The stoves

Fig. 19. Exterior View of Part of a Blast-Furnace Plant

are thick steel shells with firebrick linings and checkerwork fillings. Through one hot unit the blast always will be passing on its way from the engines to the furnace, while the others will be heating ready to take their turn at half-hour intervals.

Power Plant. In a building near the furnaces powerful engines will be at work compressing the air to go to the furnaces. These engines may be steam driven by means of boilers heated with the furnace gas; they may be gas engines driven by the furnace gas burned internally; they may be turbine engines driven by steam from gas-heated boilers. In any case, the power plant is a very important part of the plant.

Pig Casting. Fig. 19 indicates clearly enough the furnace sticking up through its casting room on the right of the picture. The gas is led from the top of the furnace through the downcomers and dust collectors across to the line of stoves and the boiler house (both in center of the picture). The power plant is the larger building on the left and behind this is the water tower for the plant supply. At the very left edge is the location of the casting machinery; the hot pig iron has to be switched over to this building in the big ladles before it is cast into pigs.

The molten iron is tapped out of the furnace and runs into ladles to go to either the steel plant or the casting machine. In the steel plant the iron probably will be poured into a large receiver and from there will be taken, still molten, to the steel furnaces. Iron to be used in trade or stored for future use is cast in molds which are strung together, conveyor fashion, so as to give continuous service. These ingots of iron, or *pigs* as they are called, fall from the casting conveyor on to flat cars for storage or transportation. An older method of casting was to run the metal out into closely packed sand molds; it is little used today. For further handling of the pigs, cranes with an electromagnet for tackle are employed.

CONSTITUTION OF IRON

COMPOSITION OF PIG IRON

Elements Present. Having studied the powerful reducing condition inside the iron blast furnace, it is no surprise to us to know that any other element present in the ore and as easily reduced as iron will come out with it as it runs from the furnace. The well-known exception to this rule is that sulphur can be fluxed off with the slag, if the slag is maintained both highly fluid and rich in lime. But the reduction goes even further than this, for, in the presence of the metallic iron, elements, not reducible otherwise, are quickly absorbed and kept from reverting back to oxide.

Thus it results that all pig iron contains more or less of silicon, manganese, phosphorus, sulphur, and small quantities of any other reducible element originally present in the ore or in the charge—these may be chromium, copper, arsenic, titanium, vanadium, etc. The iron, of course, is saturated with carbon, nearly all of which

TABLE V

Variation of Combining Elements in Pig Iron

Usage	Silicon	Sulphur	Phosphorus	Manganese	Carbon
Foundry Irons No. 1	2.75	.035	.30–1.50	.20–1.60	3.0–4.0
Foundry Irons No. 2	2.25	.045	.30–1.50	.20–1.60	3.0–4.0
Foundry Irons No. 3	1.75	.055	.30–1.50	.20–1.60	3.0–4.0
Foundry Irons No. 4	1.25	.065	.30–1.50	.20–1.60	3.0–4.0
Forge	.75–1.75	.05–.30	.30–3.0	.20–1.50	3.5–4.0
Bessemer-acid	.80–2.0	.03–.08	Under .10	.30–.50	3.5–4.0
Bessemer-basic	Under 1.0	Under .10	2.0–3.0	1.0–2.0	3.5–4.0
Open-hearth-acid	....	Under .05	Under .05	.30–.50	3.5–4.0
Open-hearth-basic	Under 1.0	....	.10–2.0	1.0–2.0	3.5–4.0
Ferromanganese	.50–1.0	Under .03	.10–1.0	80.0	5.0–7.0
Ferromanganese	Under 1.0	Under .03	.10–.50	40.0	5.0–6.0
Spiegeleisen	Under 1.0	Under .05	Under .15	15.0–30.0	5.0–6.0
Ferrosilicon	8.0–15.0	Under .07	.10–.50	....	1.0–2.0
Ferrosilicon	50.0	Under .02	Under .08	....	Under .40
Silico-Spiegel	8.0–15.0	Under .01	Under .15	15.0–20.0	1.0–1.5

will separate as graphite if it cools slowly enough, and otherwise will be in combination and make the iron white.

Physical Properties. Now, the physical properties of the material made by remelting and recasting pig iron (then called *cast iron*) will depend largely on whether the carbon is graphitic or combined in the final casting. It will fit the use for which it is intended, only if it has the right amount of graphite and the right amount of combined carbon. The size of the graphite flakes also is important. Much manganese makes the iron hard; much phosphorus makes it brittle; much sulphur makes it quite unfitted for many purposes. But the effect of each of these constituents is not only directly but indirectly through simultaneous effect on the state of the carbon. Iron of something like the compositions shown in Table V will be made for the purposes indicated.* The limits are rather wide, and, for many purposes, the right composition will be obtained by mixing irons in varying proportions.

IRON AND CARBON

Various Proportions. *Ferrite.* The scientific name of pure iron is *ferrite* which melts at 1530° C. On heating pure iron, it loses its magnetism at 768 degrees and changes its entire crystalline nature at 909 degrees; the exact converse takes place at about the

* From Stoughton, "Metallurgy of Iron and Steel".

same temperatures on cooling. The three forms of ferrite are known as *alpha*, *beta*, and *gamma* ferrite.

Ferrite is found in commerce as dead-soft steel, ingot iron, and electrolytic iron. It is impure with slag inclosures in wrought iron, and is impure with amorphous carbon separated and some silicon in solution in malleable iron.

Eutectic Point. Adding carbon to molten iron lowers the melting point until 4.3 per cent of carbon is present, when still more carbon raises the melting point even more sharply. Melts having less than 4.3 per cent of carbon freeze out a solid solution of carbon dissolved in iron which we call austenite. Melts holding more than 4.3 per cent of carbon freeze out carbides, the most important of which is Fe_3C. This carbide occurs frequently in high-carbon materials. The melt containing exactly 4.3 per cent of carbon, which freezes at 1135 degrees, is a mixture of 47.7 per cent of austenite—*austenite* being a solid solution of carbon or of iron carbide in iron—and of 52.3 per cent of cementite, and is called the *eutectic* because of having the lowest solidifying temperature of all the possible mixtures in various proportions of iron and carbon, namely, that with 4.3 per cent carbon content.

Pearlite. As indicated by the diagram, Fig. 20, austenite is stable at high temperatures only. In alloys with less than 1.7 per cent of carbon, the austenite, on sufficient cooling, separates out ferrite along a definite line, if there was less than 0.85 per cent of carbon in the solid solution; and carbide is separated out, if there was more than 0.85 per cent of carbon in the solid solution. Here, again, a minimum point is found at 0.85 per cent of carbon and 723° C. The mixture separating is called the *eutectoid*, or, more commonly, *pearlite*, because of its play of bright colors. It has 88 per cent of ferrite and 12 per cent of cementite.

Other Gradations. With the alloys of more than 1.7 per cent of carbon, austenite and cementite may decompose into ferrite and graphite, if held until equilibrium is established at high enough temperature—above 700° C. But depending largely on the *rate* of cooling, we may get all gradations between austenite and cementite mixtures, and between ferrite and graphite mixtures. Manganese, silicon, and phosphorus influence the tendency to separate graphite in strong degree.

We may, then, by adjustments of chemical composition and the rate of cooling, get an immense variety of materials in the cooled

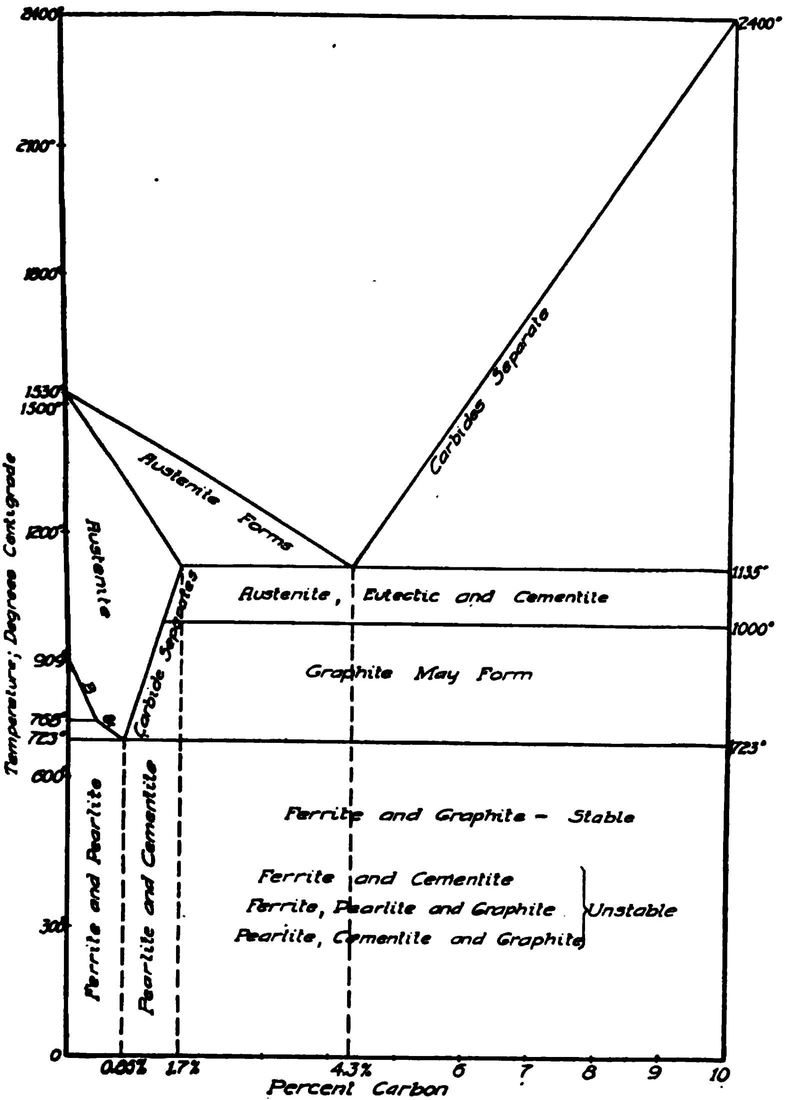


Fig. 20. Iron Carbon Equilibrium Diagram

iron at will. The art is known as *founding*. Foundry practice now is based on well-established science and is making rapid progress.

In composition the cast irons group about the eutectic mixture; likewise, the steels group about the eutectoid mixture. The diagram in Fig. 20 represents one of the greatest condensations of empirical knowledge yet accomplished in the realm of metallurgy. It can be criticized in many respects, and will be elaborated and perfected further; just as it stands, however, it can be used to enormous advantage by anybody concerned practically in the metallurgy of iron and steel.

FOUNDRY PRACTICE

Field of Operations. The great industry which annually melts some 6,000,000 tons of iron into a bewildering variety of objects, large and small, hard and soft, some for strength and some for beauty, is all too diversified for summarizing.

Foundry practice includes the blowing of pig iron to steel in small converters; the casting of the steel; and the annealing of the steel. Much ordinary carbon steel is made and, also, considerable special material, notably manganese steel.

Cast iron of course is the main material for the foundry. Brass founding is much more restricted in tonnage and scope, and the metal also is melted usually in crucibles. The latter product cannot compare in structural diversity with that made in the former and more important branch of founding.

Furnaces. *Cupola.* Most foundries melt their iron in shaft furnaces, called cupolas, with the aid of coke and a little flux. Cupolas range in internal diameter from 20 inches to 10 feet. The proper mixture is charged into the cupola as it melts down, while ladleful after ladleful is tapped out of the crucible as the proper amount collects inside. If the cupola is large enough to run continuously, the metal will be poured from a large receiving ladle into smaller ones for transfer to the molds.

Open Hearth. The best cast iron is made by melting the pig in small reverberatories or in open-hearth steel furnaces. This keeps the phosphorus and sulphur of the fuel from getting into the iron, and admits of making large melts of uniform and precise specifications.

Molds. *Varieties.* For some purposes the molds to receive the metal are made of iron or steel; usually they are of a porous, tenacious, and highly siliceous sand. The molds may be made up of a

damp mixture inside proper supports; and they then will be termed *green-sand* molds. If the mold is baked hard after the shaping, it will be known as a *dry-sand* mold.

Cast Iron. *White.* White cast iron has all the carbon in the combined condition as produced by proper composition and quick cooling. This white, or chilled, iron is used for carwheel rims out-

Fig. 21. Medium-Grain Cast Iron, Showing Graphite, Pearlite, and Cementite

side a spider of gray iron; it is used for crusher jaws for roll shells, for the rolls of rolling mills, or wherever a hard resistant surface is demanded.

Gray. Gray cast iron should contain little or no free carbide but should have the carbon mainly as graphite; it is used for numberless objects, from kitchen utensils to engine beds weighing many tons. Often gray-iron castings are made soft enough to machine with steel tools and so to be of precise dimensions.

Malleable. For making malleable iron the castings are first made chilled; they are then taken from the molds and assembled in rooms, to be heated for some days to a bright red heat while the carbon separates in the amorphous state and the metal assumes the properties of quite pure ferrite.

Specimen Structure. Fig. 21 shows what a rather hard cast iron looks like when polished, etched, and magnified 200 diameters. The black spots are graphite; they make cast iron soft and lubricate the cutting steel. The white spots are free carbide; this substance makes iron hard and brittle and dulls the cutting tool; soft iron should have no such white spots, for all this carbide (Fe_3C) should have decomposed to ferrite and graphite while the iron was hot. The intermediate gray areas are pearlite; it is this substance which makes iron strong. An iron composed entirely of this structure would be a steel, and could be treated and used just as all steels are; one sees that irons and steels really are related closely. The high carbon content of irons, usually present as graphite, is the main difference between irons and steels.

Expert Ability Required. In the foundry there is much about the cupola requiring extensive scientific and technical knowledge. Conditions of mixing and melting cannot be studied too thoroughly.

The preparation of the molds is another department demanding expert knowledge. The production of the shapes, the composition and character of the sands, the manipulation of the patterns, and the finishing of the objects all call for scientific as well as for practical attainment. In the more numerous small plants one often sees founding unfortunately botched by ignorant management and labor.

WROUGHT IRON

Process. At one time, wrought iron was far more important, relatively, than it is now. As a matter of fact it is surprising that the process can survive at all. The process is essentially a melting of pig iron, a burning out of the phosphorus and carbon with the aid of iron oxide, and a final massing of the ferrite—now of much higher melting temperature—with working and shaping through rolls into commercial bars. Simple coal-fired furnaces are used.

Status. The furnaces used are necessarily of limited size; fuel consumption is excessive; labor is arduous; and the product is

anything but uniform. To a considerable extent the industry has fallen into busheling or bundling steel scrap in a reverberatory furnace somewhat larger than the genuine puddling furnace, then putting it through the regulation finishing as for real wrought iron. The product hardly can be considered desirable.

Wrought iron holds its small place largely through custom and its ability to weld easily. It is most excellent for many purposes, but it has a losing fight against steel that is equally good and cheaper.

MANUFACTURE OF STEEL

CARBONIZING SOLID IRON

Process. This is the oldest method of making steel; it is known as the *cementation process* and practically is superseded at the present time. The process consists of heating wrought iron in a packing of charcoal to a high enough temperature so that the solid solution of cementite in iron will gradually diffuse through the entire metal. As formerly carried out to a limited extent, especially at Sheffield, England, long bars of wrought iron were packed in large receptacles, the charcoal filling up between and around the bars. This whole receptacle—enclosed within still another wall, as in a furnace—was brought up to heat gradually and was maintained at something over 700° C. during 7 to 10 days longer, depending on the grade of steel to be produced. Though the process is extremely inefficient, and the product equally varied, it survives in its modern application as casehardening.

Modern Casehardening. *Casehardening* is the production of a thin layer of steel on the outside of a much lower carbon metal. Recent practice does not confine itself to using charcoal alone, but, depending on the material and purposes, the carbonizing medium may be either charcoal and highly carbonaceous materials, or carbon-bearing gases, or even molten solids which may give to the iron object part of their carbon.

Casehardened objects are fairly common in ordinary life and have especially useful application in that the center of the material may be strong and tough although its exterior will be hard and brittle and take a fine polish. Such objects are common in all sorts of machines, such as bicycles, automobiles, and wherever ball bearings and wearing surfaces are found.

CRUCIBLE STEEL

Process. *Original.* The invention of the process of making crucible steel by Huntsman, near Sheffield, England, in 1740, was a great advance in the art of making steel. He melted bars of cemented steel in small crucibles and thus got ingots of much greater uniformity. In succeeding decades men learned how to melt purer iron with carbonaceous materials and to introduce the requisite amount of manganese for making very high-grade material.

Present Method. As practiced today, wrought iron, or scraps of good-quality soft steel, are melted in fire-clay or graphite crucibles

Fig. 22. Working Ingots at a Crucible Steel Furnace
Courtesy of The Colonial Steel Company, Pittsburgh, Pennsylvania

holding about 100 pounds of metal in furnaces heated by coke or gas. The requisite amounts of carbonaceous alloying ingredients will be dissolved, as the metal liquefies at a necessarily very high temperature, and, after standing for some time to become a perfect liquid, the metal may be deoxidized with a bit of metallic aluminum and then poured carefully into ingot molds.

Fig. 22 shows the men working at such a crucible furnace. Such a furnace is hardly more than a melting hole into which are led the pre-heated gas and air to combine about the crucibles. The furnace is

run regeneratively, as will be explained further in the section on Open-Hearth Steel, with the gas supplied by gas-producers. One gets a good idea of the size of the crucibles, of the intense heat, and of the methods of handling the crucibles from this picture.

Status. The manufacture of crucible steel still is carried out on a considerable scale, but, as the process never has overcome the defects of extremely small melts and much hand labor, it has lost relatively, in comparison with the tonnage processes. The process requires much skill, and is even yet being perfected in various details. There still is a strong demand for such material, especially for high-grade alloyed steels with the remarkable properties developed by the use of nickel, manganese, chromium, and tungsten.

BESSEMER STEEL

History. During the fifties of the last century, Kelly, in the United States, and Bessemer, in England, both discovered that the carbon could be burned out of pig iron simply by blowing air through the molten metal. The Englishman was very fortunate in his aggressiveness and the prevailing conditions, and in a few years was able to develop his process so as to make a very good grade of steel immensely cheaper than it ever had been done before. Bessemer developed the furnace, almost as it is used today, and the process has been continued with comparatively little change since the time of his early successes.

Converter. All converters have nearly the same shape and are operated in about the same way. Fig. 23 shows a round body with detachable bottom. The outer casing is of heavy steel plate. It is filled and emptied through the nose A. The current of cold air enters through the pipe C, and passes through the trunnion T. It enters the converter from the windbox B, passing through the tuyeres F. The tuyeres are of fire brick 24 to 28 inches long, and have 19 holes $\frac{5}{16}$ inch in diameter, or 7 holes $\frac{3}{8}$ inch in diameter. The trunnion rings N are fastened to the converter, which turns on the supports for the trunnions. The bottom is coupled on with clamps and can be removed and replaced with a fresh bottom in a few minutes.

Process. *Principle.* In principle, the process depends upon establishing a bath of molten pig iron in a suitable receptacle provided with apertures for blowing in air, which, when it comes into

contact with the hot metal, oxidizes with avidity whatever silicon, manganese, or carbon is present, and even may attack the iron itself, if the blowing is not discontinued just as the carbon is burned out. The metal thus obtained is alloyed with exactly the right amount of carbon and manganese and is cast into ingots.

Variations. Variations of the process consist in using phosphorus as the internal fuel, as can be done when using high-phosphorus

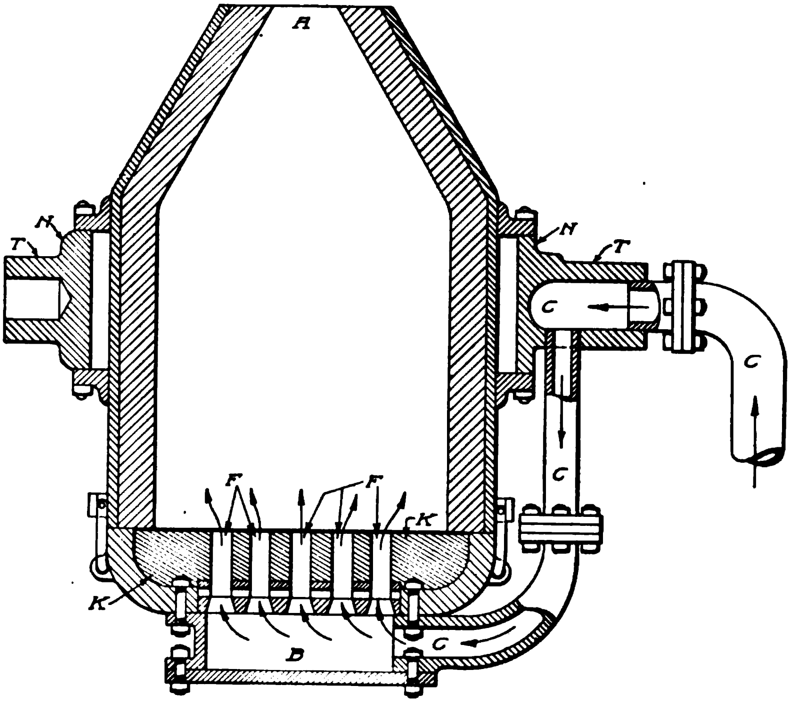


Fig. 23. Section of Round Body Converter with Detachable Bottom

pig iron and a converter which is lined with a basic instead of a siliceous refractory. By very careful work, and as practiced in some countries, the process can be stopped at exactly the right carbon content, without having first to burn out all the carbon and then to put back the right amount. American practice has found that the latter is the quicker method and that it gives good results. A surprising amount of heat is developed during the reaction, and the process must be regulated carefully. In using the acid process, one is unable to remove phosphorus and sulphur from the metal.

This gradually has narrowed American practice down to the use of pig iron or what is known as *Bessemer* grade, and the process has suffered much in comparison with the development of the open-hearth process, next to be described, which is slower but can be adjusted more at leisure.

Future Possibilities. As Bessemerizing is the most rapid and efficient method ever discovered for making steel out of iron, its further extensive use may have considerable future as part of a complex process in which the phosphorus in pig iron will be eliminated in the open-hearth furnace, the carbon eliminated in a converter, and the metal then considered finished—or given a further extra refining in an electric furnace which will bring the sulphur to a very low limit.

OPEN-HEARTH STEEL

History. *Development of Regenerative Heating.* At about the time Bessemer was developing his process, other men were perfecting an improved reverberatory furnace. Steel-making temperatures had been obtained in small coke-fired furnaces, but were found impossible in large furnaces until Sir William Siemens tried the pre-heating of gas and air before allowing them to combine over the hearth of the furnace. Pre-heating the air, by the alternated passing of the waste gases and incoming air through a fire-brick checkerwork, made possible the attaining of a temperature entirely new for refractory furnaces. This is called *regenerative heating;* the checkerworks are called *regenerators.* The new furnace of course was developed largely with the idea of making steel in it, and it soon came into successful commercial operation.

Status. The open-hearth furnace, with its accessories, has been brought to a high state of adaptability and efficiency. It can be heated with any sort of combustible gas, oil, or tar; the manual labor has been reduced to the minimum by all sorts of mechanical appliances; and the tonnage capacity has been continually increased —many furnaces now are able to put through 300 tons in 24 hours. It is by far the most important method for making steel which the world has today. Its drawbacks are in its inability to change its temperature range quickly, and a rather necessary slowness in burning out carbon, as the gas produced by a too rapid burning from

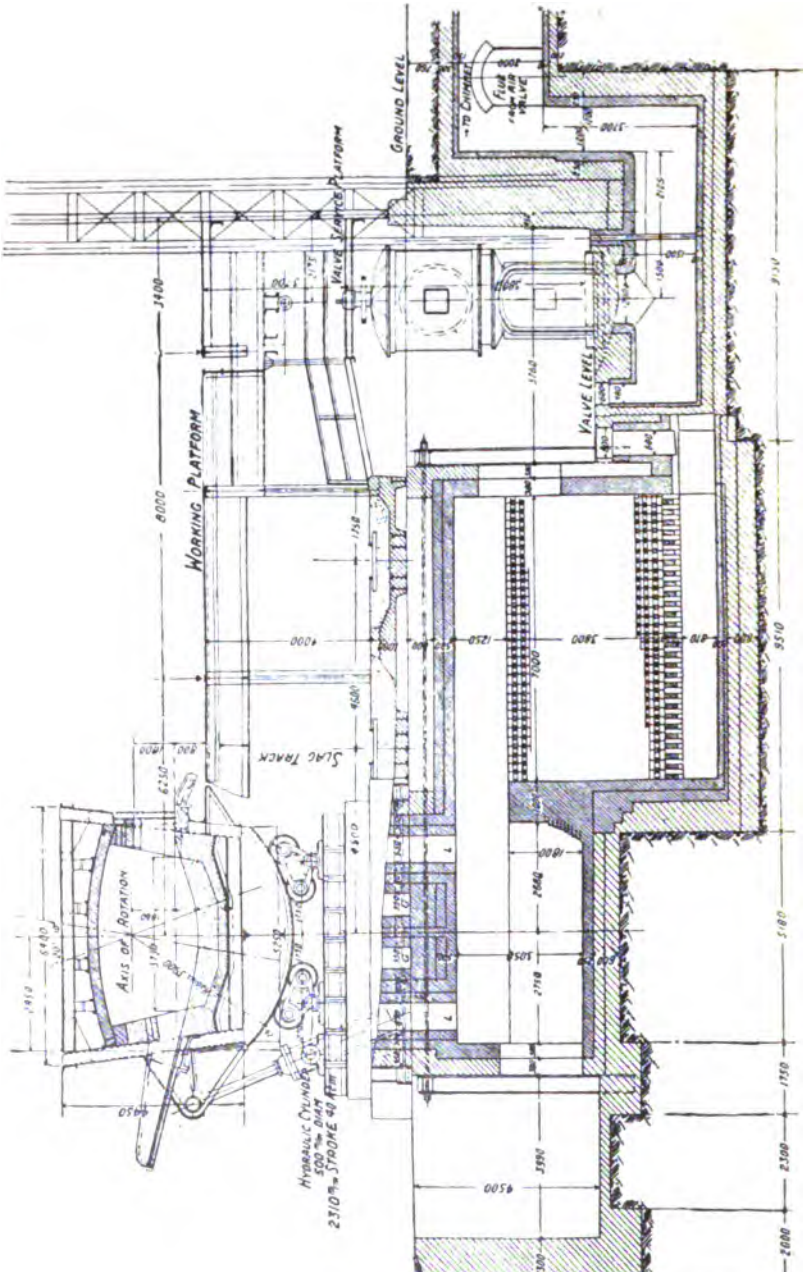


Fig. 24. Section through Large Austrian Open-Hearth Furnace
Courtesy of the "Iron Age"

solid or liquid ingredients in such a large bath would make the metal boil out of any reasonably sized furnace. Although it is such a well-established process at the present time, its combination with other processes, as mentioned in the section on Bessemer Steel, has more than pretensions for such possible future usefulness.

Furnace. Fig. 24 is a section through an open-hearth furnace of a European plant. It is a tilting furnace moved by the hydraulic piston as indicated. The furnace is charged from the working plat-

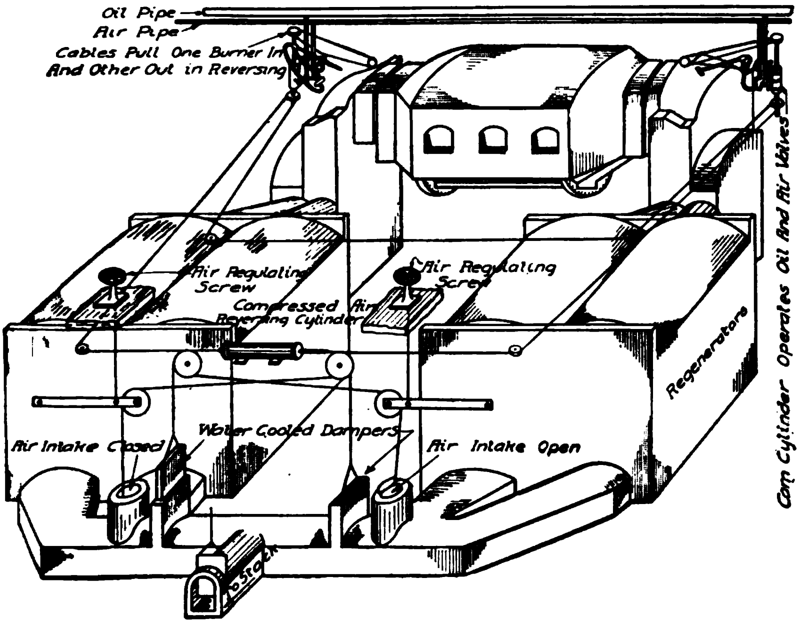


Fig. 25. Perspective Diagram of Open-Hearth Furnace
Courtesy of American Institute of Mining Engineers

form, and the metal is poured from the spout on the opposite side. The checkerwork for heating the gas and air is indicated in the center of the section and below the furnace level. The dust chamber is at the end of the flues directly down from the end of the furnace; a passage leads to the checker chamber. From the checkers ducts lead to the right to the gas and air inlets and to the stack; the valves are located here. In this figure all dimensions are in millimeters.

A perspective giving an excellent idea of the relative positions of the furnace, ducts, checker room, and dampers is shown in Fig. 25.

This furnace is oil-fired, so only the air has to be pre-heated. The diagram shows how all the dampers are reversed when the waste gases are switched from one checker room to the other. The student should follow the actions of all the valves which result from reversing the air cylinder and from adjusting the air-regulating screws. The draft through the stack is depended upon to pick up the gases from the hearth and to pull them through the regenerators.

Variations. The open-hearth furnace may be either stationary or tilting; its hearth refractory may be either siliceous or basic; the walls and roofs commonly will be of silica brick; the ports at each end of the hearth which admit the heated air and pass the burned gas suffer much from the high temperature and now usually are made sectional so that they can be replaced without interrupting operations except for a few minutes. Flues lead from the ports down to the checkerwork where the air and gas will be pre-heated. If either oil or tar is used, pressure steam will blow the liquid into the furnace through a nozzle, and only air will have to pass through the checkerwork. Sufficient valves are provided in the flues for reversing the currents and for regulating the draft. It is not unusual now to find waste-heat boilers beyond the checkerwork so that the gases coming up the stack will have given up most of their available energy.

Process. In the process using a basic bath, the pig iron used is preferably rather high in manganese so as to remove as much sulphur as possible during the process. Scrap material is a common ingredient of the charge; iron ore also is used; while varying amounts of lime will be added to combine with the phosphorus present as it is oxidized and removed as slag. After some hours, the phosphorus having been slagged away sufficiently and removed, and the carbon being reduced to about the right percentage, the metal is tapped into a large ladle, deoxidized with metallic aluminum, and the manganese brought to the right specification by the addition of ferromanganese, and then, after standing a few minutes, the steel is teemed from the ladle into the ingot molds.

Modified Forms. The process can be hastened by certain modifications, which gives rise to the special processes known as the Talbot process, the Monell process, the Campbell process, or to the use of a converter to finish the metal after the phosphorus has been eliminated.

INGOTS

Defects of Solidification. We have learned in considering the general properties of metals that they always crystalize upon solidification. This is eminently so in the case of the molten steel solidifying in the large ingots of commercial operations. These masses of steel, often weighing many tons, aggravate the segregation of impurities by the necessarily long time which elapses before the interior of such an ingot becomes entirely solid.

Segregating. Because of this characteristic solidification phenomenon—the growth of the crystals from the exterior to the heart of the ingot during the solidification—it is found that ordinary ingots exhibit wide variations in their chemical compositions. Carbon may vary many per cent of its total amount, as between the outer shell and the core. Phosphorus often is worse in this respect, and the same is the case with sulphur. Elements which form solid solutions with ferrite in the cold show little tendency to segregate. It is those elements which are thrown out of solution in ferrite—and in so doing form low fusing alloys and eutectics—which not only segregate most but are injurious because of this segregation in the finished material. This is known as *segregation* in steel, and is one of the great features to contend with in modern practice.

Piping. Another phenomenon exhibited by steel in solidifying is the contraction of the metal during the solidification and cooling of the solid; the effect is that the metal solidifying in its exterior portion has a solid shell formed, against which the molten interior gradually is contracting and solidifying. Obviously, a hole will be left in the very heart of the ingot when all of the metal has become solid. This cavity is called the *pipe.* It is a very serious defect in any ingot, because, if it is not removed, it will leave a flaw in the finished steel.

Blowholes. Another defect in many ingots is caused by gases, which were perfectly soluble in the molten material, extruding into little blowholes as the metal assumes the solid state. This condition possibly is more peculiar to converter practice than to any of the other methods, and it needs the most careful technique to overcome it fully.

Specimens. As shown in Fig. 26, Ingot No. 1 plainly is damaged seriously by the presence of the large blowholes throughout the

entire metal; as the steel solidified, this gas generation even forced the metal *up* in the mold. Ingot No. 2 has a few blowholes about the outside of the ingot and a core of conspicuously segregated metal, the pipe is small. Ingot No. 3 has a most aggravating pipe but is otherwise sound; to cut out the piped part as discard would mean losing half the ingot. Ingot No. 4 is sound with a big cavity in the feeder head; when this head is cut away, 95 per cent of the ingot may

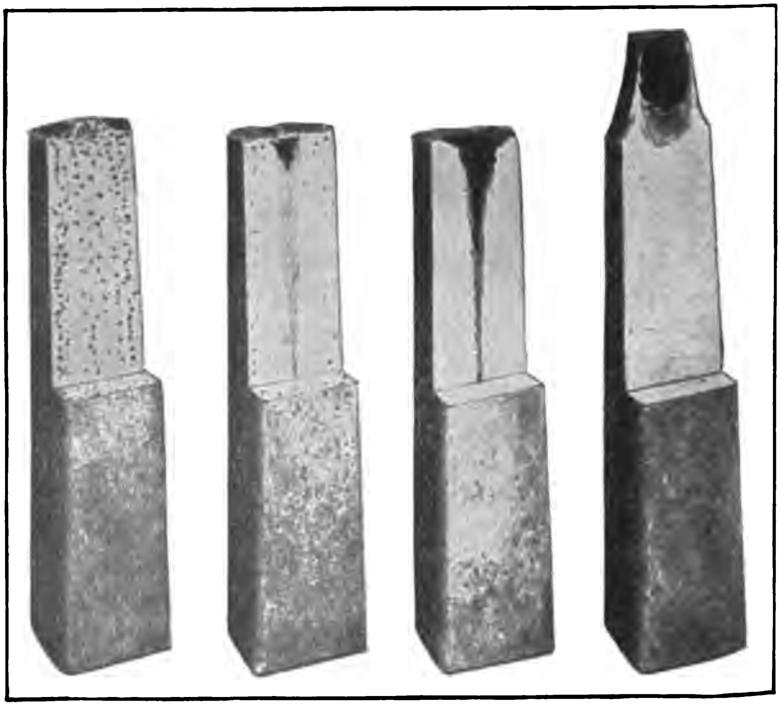


Fig. 26. Three Bad Ingots and One Good One, Showing the Method of Testing the Steel Ingots
Courtesy of the American Institute of Mining Engineers

be sent to the mill in perfect condition. The first three ingots show what may happen in ordinary practice; the fourth shows what scientific study will accomplish.

Remedying Defects. The presence of small particles of solid foreign materials—like slag and oxides—in the ingot, as well as of defects like cracks and checks, is a matter of faulty operation and does not require the serious study to overcome as in the case of segregation, pipes, and blowholes.

Methods. To overcome all these defects is one of the serious efforts of current study. We know that small ingots, as a rule, are not affected as seriously as the large ingots, but it is seldom practical to resort to this. Bottom casting of the ingots is not infrequently used and gives a much better metal than the ordinary teeming.

A pouring basin on top of the mold may be a step in the right direction but is only a partial remedy. Casting ingots with the big end uppermost, and with the mold very thick at the base, much reduces the defect due to the pipe. The intrusion of a can of thermit into the very bottom of the still molten metal at the proper moment has proved efficacious and worth using. Squeezing the ingot while the core is still partly molten of course will close up any cavity and give a solid ingot. Heating the top of the ingot and keeping it molten as long as possible will concentrate the cavity in the very top of the ingot and prevent much metal being wasted when the ingot is cropped preparatory to rolling.

Particular chemical composition to a certain extent can regulate the amount and position of any blowholes which will be formed. Finally, the technique of deoxidizing and recarbonizing will have an extreme effect on the solidity and uniformity of the solid ingot. Gases must be removed as completely as possible while the metal still is molten; slag particles and particles of oxide must be floated to the top of the bath while the metal is held fluid. This chemical and physical purification is accomplished by using the proper deoxidizers in exactly the right amount. The most common deoxidizers are aluminum, ferromanganese, ferrosilicon, ferrotitanium, and ferrovanadium.

MECHANICAL TREATMENT

Importance. The mechanical treatment of steel, through its influence on the structural units of the metal, is as important as any phase in the production of a suitable finished product. It has the most profound result in perfecting the physical internal structure of the metal, as well as in shaping it for the use desired. The four great methods of shaping metal are: (1) pounding or hammering; (2) rolling; (3) squeezing in hydraulic process; and (4) drawing through dies, as in the making of thin bars and wires. Each of these

methods of shaping is especially efficient in making products of certain shapes and will be favored on that account.

Hammering. Hammering is the most ancient method, and is used largely still, in connection with the crucible process. Hammers have been built to very large size, but are subject to certain mechanical defects and cannot compete with other methods of forming in the shaping of most objects. Hammering gives an especially good working of the surface layers of any object, but, as the impact is so transient, the core of the metal is less worked by this than by any of the other three methods.

Rolling. Rolling of the metal is the most rapid of all the processes for shaping. If the metal is used at a rather high temperature, it will offer little resistance to shaping and can be passed through the rolls at an extremely rapid rate. Care must be taken always that rolling speeds are not too great nor the exterior layers drawn by excessive differential motions. The effect of squeezing in rolls is more prolonged than by hammering, and rolled material may have a well worked core. The metallurgist is especially interested in this mechanical kneading of the metal as it passes through the rolls, but also must be thoroughly familiar with the mechanical side of the treatment.

Mills. Rolling mills are built in conjunction with nearly all steel plants, and shape up the material into billets, slabs, bars, plates, rails, structural forms, and the other simple shapes used in commerce. Of the divers sorts of mills for working everything from ingots to finished shapes we can show only one—a blooming mill, or that for the first passes of large ingots. The self-acting rollers of the tables at both ends of the rolls, Fig. 27, hurry the heavy lengths of metal into the gap between the two horizontal rolls which revolve now in one direction, now in the other, according to the pass. Each time the rolls will be closed a little between passes so that the ingot soon is reduced much in cross-section and is made longer. The driving mechanism is in the room at the right; the gears to make both rolls turn together are in the box at the right end of the two spindles which are coupled to the actual rolls. Above the roll frame is the mechanism to raise and lower the rolls as the pass demands. The motors to drive the live rolls of the tables are in the center foreground.

Pressing. Hydraulic presses with their slower movement give the most penetrating compression to metal and cause a more thorough

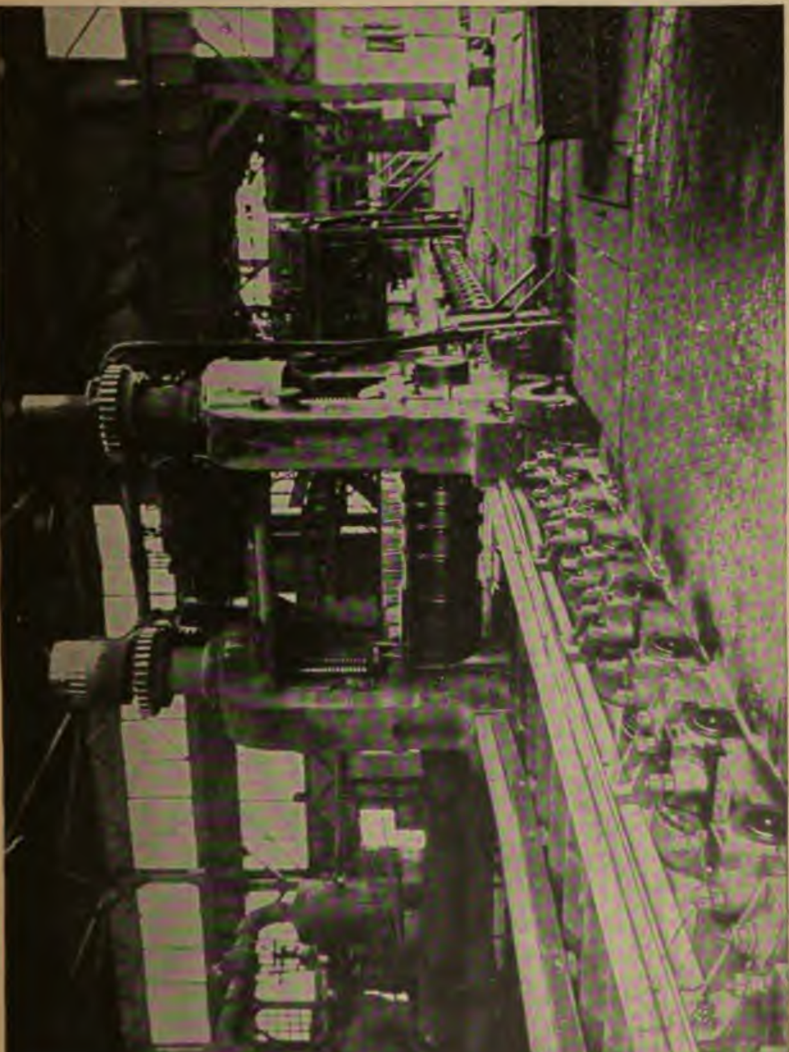


Fig. 27. Typical Blooming Mill, Showing Forming Rolls Mounted in the Machine

deformation than any of the other methods. For this reason the internal fine grain so desired is better attained in this than in any other working process in use. Fig. 28 is a picture of an enormous

hydraulic press about to reduce the size of an ingot. With many turnings and squeeze after squeeze such a broad thick ingot gradually will be drawn out into gun tubes or shapes for other objects.

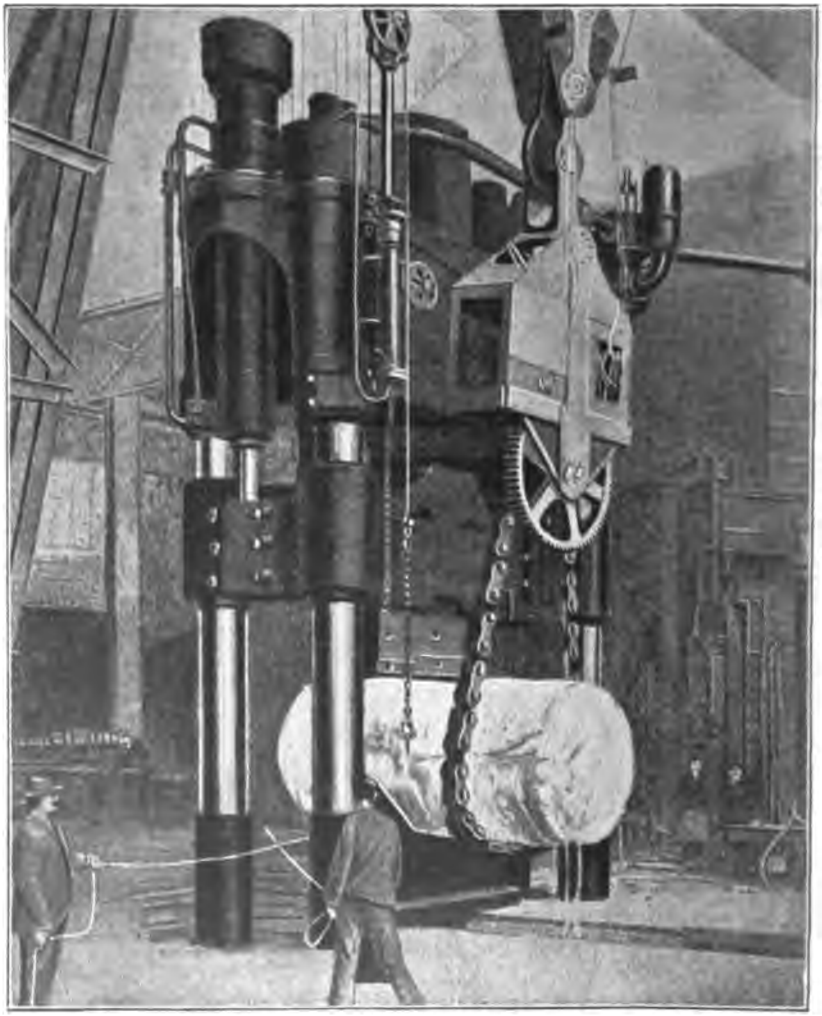


Fig. 28. Immense Forging Press Installed in Krupp Works, Germany

Hydraulic Press Elements. While the parts of a press such as can be seen in Fig. 28 are essential and comprise as their principal features the upper and lower forging bitts properly connected—

the main columns supporting the hydraulic compression cylinder and the two side lifting cylinders, the movable head, the attachments for turning and moving the ingot, etc., yet the mechanical means for supplying the power to the press and causing quick and repeated actions are equally essential and have made a great success for the machine.

Drawing. Wire drawing gives good internal working to a metal but of course is limited to the peculiar forms which can be made by such a process. As a matter of fact, the strongest metal ever produced has been made by a suitable combination of annealings and drawings.

HEAT TREATMENT

Ordinary Materials. Heat treatment of steel is a matter of the utmost importance and is absolutely essential for making the best materials. It is fortunate that the mechanical shaping of steel is done commonly at a temperature which gives the material good properties when finished. Thus, in the making of things like steel beams or steel rails, the heating and shaping have been carried out together, and, as the metal cools off, it is suitable for use. The lower the carbon content of a steel, the less the heat treatment will affect its final condition.

Tonnage Production. These general statements are good for materials requiring no unusual properties. Thus rail steel needs to have only the normal structure for a steel of the right manganese and carbon content to give normal material. If the manganese is about right, if the carbon is medium—that is from 0.50 to 0.75 per cent—and if the material has been rolled properly, there results a good material for rails. The same in general holds for structural steel, while in the case of many sheets which are of lower carbon steel, they are suitable for use as they come from the rolling mill. In the great tonnage of steel production it is essential only that the chemical composition shall be right approximately and that the mechanical working shall have been done at a suitable temperature with normal cooling.

Special Materials. But there are many more cases, not so much on a tonnage basis as for small units for special uses, where the normal material would be utterly inapplicable. These in particular

are where objects are to be of hardened steel, and where they should be of tempered steel. We can get hard materials by the right chemical composition and with slight attention to any heat treatment, but, by having the carbon content exactly of the right amount and by cooling the material suddenly, very hard steels can be produced without further alloying.

Tempered Steels. All such hardened steels are apt to be unduly brittle and suitable for use usually only as the cutting or wearing edge of an instrument or tool. But by taking this hardened material and heating it carefully to such a temperature that the austenitic structure will begin to break up into the structures more stable at lower temperatures, we are able to get materials which will be intermediate and have not only considerable hardness but much increased strength and toughness. These in general are the tempered steels; they are the steels in which great tensile strength is required and which are especially desirable for innumerable uses, since, with the great strength, the bulk or size of the object can be kept small. The tempered steels are particularly useful for all sorts of tools and implements, and also are used widely in all classes of machines. Most of the working parts of the distinctively modern machines, such as flying machines, automobiles, and submarines, as well as innumerable locomotive and stationary-engine parts are made of such materials.

Effects of Temperature. *Working Limits.* The temperature at which metal is to be worked should be graded entirely by the finishing temperature which well may be about 700° C. The more mechanical working there is to be done, the higher must be the initial temperature; on the other hand, an initial temperature of over 1150° C. hardly is to be desired; accordingly, with much working to do, this means that reheating is the logical conclusion.

Variation of Structure. Again, the most quickly chilled steel will have an austenitic structure, and a steel just annealed to full softness will have a very finely pearlitic structure. The various stages through the changes from this first to this second stage correspond to the decomposition stages of the solid solution and to the formation of the pearlite; they are designated *martensite, troostite, osmondite,* and *sorbite.* Tempering is the production of one or more of these special structures; it makes no difference how the structure is obtained.

TABLE VI

Chemical Composition of Ferrous Materials

Material	C		Elements Present Other Than Iron (Per Cent)							
	Total	Free	Mn	Si	P	S	Ni	V	W	Cr
Iron:										
Cast	2.6–3.8	2.5–3.5	.3–.7	.5–2.8	.4–1.0	.05				
Chilled	2.5		1.0	.5	.05	.1				
Malleable	3.0	3.0	.25–.6	.5–1.0	.15	.05				
Wrought	.1		.1	.1	.2	.1				
Electrolytic	.004		.000	.004	.001	.002				
Ingot	.008		.04	.003	.005	.03				
Steel:										
Castings	.2–1.0		.4–1.0	.4–.5	.06	.05				
Rails	.35–.75		.8	.2	.02–.1	.05				
Structural	.25		.5	.1	.04	.03				
Tool	.89		.3	.25	.02	.03				
Nickel	.30		.5		.06	.05	3.0			
Manganese	1.5		12.0	.3	.06	.02				
Silicon	.1		.3	3.0	.05	.03				
Armor plate	.25		.2–.6	.15	.04	.03	3.5	.15		1.8
High-speed	.70		.4	.2	.05	.04		(.2)	17.0	3.5
Vanadium	.2–.5		.2–.5		.05	.04		.15		

In practice, tempering may be a chilling somewhat slower than a real quenching, as in molten lead or in oil; or it may be a chilling in a water or a brine solution, and a subsequent reheating until the proper structure is developed, which will be made permanent by chilling from the second drawing temperature. The cutting edge of a tool which has been quenched is reheated by withdrawing it and letting the heat from behind follow down until the drawing is exactly right, after which the entire head of the tool is quenched.

In the high-speed steels these structures are spread out and highly differentiated, and are obtainable with much precision. In the straight carbon steels it is difficult thus to separate them, so that the most expert knowledge is required to get a thick piece of the same tempered structure throughout.

Many Factors Affecting Material. In studying such an arrangement as that in Table VI, it must be kept in mind that the chemical specification is no more than one of many factors determining the quality and the properties of the material. The *method of manufacture,* whether crucible, Bessemer, or open-hearth furnace, or the acid or the basic process; the *manner of shaping;* the *heat treatment;* the *physical properties,* such as tensile strength, are all often just as important as chemical composition.

ELECTRIC FURNACES IN IRON AND STEEL MANUFACTURE

Furnaces for Pig-Iron Production. Electric furnaces for making pig iron are meeting with some success in centers where electricity is cheapest and where iron ore also is available; this is possible in localities in the Scandinavian countries and in California.

Arc-and-Resistance Type. Fig. 29 is a diagram of an electric furnace making pig iron; it is the combination arc-and-resistance type, continuously operated. The construction of this furnace

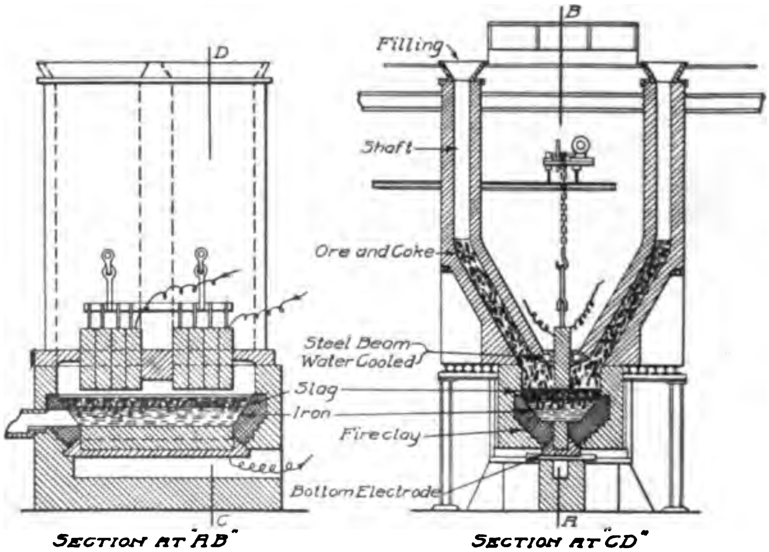


Fig. 29. End and Side Sectional Elevations of an Electric Furnace for Making Pig Iron
Courtesy of the "Iron Age"

differs somewhat from that of others which are in use but the principles and chemistry involved are the same in all and will be obvious after having studied the iron blast furnace. A furnace like that of Fig. 29 is heated by the current through the electrodes as indicated in the cut. The coke fed in with the ore effects the main part of the reduction; gases formed by the combustion may be circulated up through the column of ore to give as much pre-heating and reduction as possible.

Furnaces for Making Steel. Electric furnaces for making steel excel in that no current of gas has to pass through or over the metal, and in the high temperature which can be obtained readily. Only

where electricity is wonderfully cheap, do these furnaces prove economical in the reducing of iron from its ores, in the melting of cold metal, or in the comparatively low temperature heating and slagging period which is necessary for the removal of phosphorus from the metal.

Pure-Arc Type. Fig. 30 is a section through the Stassano pure-arc type of furnace. The electrodes are entirely above the charge which is heated by radiation. Mechanical arrangement provides

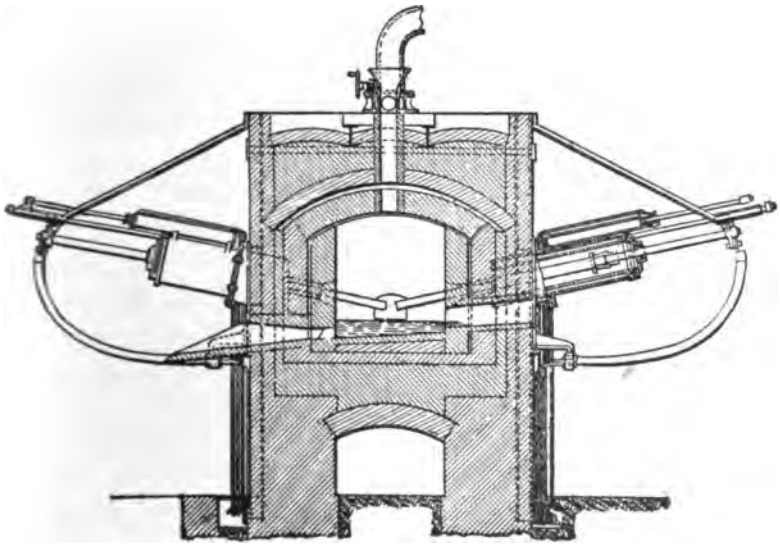


Fig. 30. Section of Pure-Arc Type of Electric Steel Furnace
Courtesy of the "Engineering and Mining Journal"

for turning the furnace about to give motion to the bath. Quite a number of these furnaces are in use.

Combination Type: The furnace most used resembles the type of Fig. 31, which is of Heroult make. It is obviously a tilting furnace. No electrodes are shown in place in the picture but are to be inserted in the two large holders suspended above the furnace. Such furnaces require many thousands of amperes, with the voltage usually less than 100; the electricity is for heating only, the heat is partly from the arc between the electrode and the slag and partly because of the resistance through the bath. The current comes in at one electrode and goes out at the other.

Advantages of High Temperature. The electric furnace has a real field of usefulness in the final removal of sulphur from a partly purified bath, because we can get a very liquid slag and a very basic slag by using sufficiently high temperature, such as cannot be obtained in any other type of furnace. Electric furnaces, of course, may be lined with either an acid or a basic refractory, depending on whether we wish to make an acid or a basic slag. As intimated by the possibility of sulphur removal just mentioned, most furnaces now are lined with basic material.

Fig. 31. Heroult Type of Electric Steel Furnace
Courtesy of the "Iron Age"

The most common type of electric furnace is the combination arc-resistance type in which the heat is partly developed by the arc between electrode and slag and partly by the resistance which the slag and metal offer to the passage of the current. Extremely high temperatures thus are attainable, and thinly fluid slags often containing much calcium carbide are obtained, which would be absolutely infusible in any other type of furnace. Such a high-lime slag is very efficacious in fluxing off even small amounts of sulphur from the metal. Otherwise, the chemistry of the electric furnace is no different from that of other types of furnaces. Carbon is easily introduced by adding varying amounts of pig iron, or is burned out by adding iron ore.

Status. The tonnage of electric steel is increasing year by year, and furnaces holding 20 tons in one charge are now operating. Of the 215 electric steel furnaces in the world (1915) 75 are of the type of Fig. 31. All the furnaces now in the world have a combined yearly capacity of over a million tons of steel.

MISCELLANEOUS METALS

COPPER

Important Characteristics. In the United States coal is the most valuable mineral product, pig iron is the next most valuable, and copper comes third with a yearly production of over a half million tons and a value of over $150,000,000.

Although in a general way copper is not nearly so vital to our mode of existence as iron is, since iron is the basis of our activities, yet copper allows variation in color and finish, and—through its extensive application in all electrical work—gives a breadth and convenience to many sides of our life which now would be discarded with much regret.

The mines and plants from one end of the country to the other are open to visitors, and the industry seems permeated with broad-minded and kindly-disposed men who do not fail to grace the literature, until it is a better reflection of the industry than is the case with any other technical subject of which the author knows.

The great hydrometallurgical copper mine of the world has been at Rio Tinto, Spain; that will still continue to be a great mine, but will be dwarfed by the tonnage and technique of the remarkable Chuquicamata mines of Chili which are now being brought to capacity by American enterprise.

Copper Minerals. Copper occurs in the following forms:

Native Copper. This is the mineral of the Lake Superior copper mines, and it occurs also in many other ore deposits.

Cuprite. The red oxide, Cu_2O, a mineral very high in copper, enriches many western deposits.

Tenorite. The black oxide, CuO, is a less important mineral but is found frequently in many mines.

Malachite. The green carbonate, $CuCO_3.Cu(OH)_2$, is a very conspicuous and important surface mineral.

Azurite. The blue carbonate, $2CuCO_3.Cu(OH)_2$, often accompanies malachite.

Chryscolla. The silicate, $CuSiO_3.2H_2O$; also is a surface mineral.

Chalcopyrite. The copper pyrites, $Cu_2S.Fe_2S_3$, form the universal and most important copper mineral.

Covellite. The sulphide, CuS, is found as one of the main deposits of the Butte district.

Chalcocite. The mineral, Cu_2S, is very common and important in many western mines.

Bornite; Enargite; and *Tetrahedrite.* These are complex minerals of note.

Brochantite. The basic sulphate, $CuSO_4.3Cu(OH)_2$, is the mineral of the Chuquicamata mine.

REDUCING COPPER ORES

Methods. Of the several methods of reducing copper ores outlined below there are now only two of minor importance—strong reduction, and pyritic smelting for sulphide ores. All the others at present are operating on very extensive scales. The old Welsh processes of roastings and reductions are of only theoretical and historical interest.

I. *Smelting by Fire Treatment Alone.*
- (A) Oxide ores smelted in blast furnaces to black copper.
- (B) Sulphide ores smelted in blast furnace to matte; matte converted to blister.
  - (1) Strong reduction for low-sulphur ores.
  - (2) Semipyritic smelting for medium-sulphur ores.
  - (3) Pyritic smelting for high-sulphur silicious ores.

II. *Combination Wet and Fire Recovery.*
- (A) Reverberatory smelting to bullion and slag.
- (B) Mechanical roasting; then reverberatory smelting to matte.

III. *Hydrometallurgical Recovery.*
- (A) Sulphide ores leached with acid solution, and copper precipitated as metal with iron.
- (B) Sulphate ore leached with acid solution, and copper precipitated as cathode metal by electricity.

Oxide Copper Smelting

Process. Smelting oxidized copper ores to black copper, as the metal thus recovered is called, is one of the simplest of all smelting operations. The ore with flux and coke is charged into a suitable cold blast furnace; the metal is collected in the crucible until enough is present to tap out into the ingot molds.

Fig. 32 shows in perspective and section a round copper blast furnace; the larger rectangular furnaces are built with close adherence to the proportions as seen in the round type. The interior is rather short and wide—not much height is required to effect reduction of the metal; water jackets inclose the smelting zone and the charge column up to the feed floor. The metal collects inside until

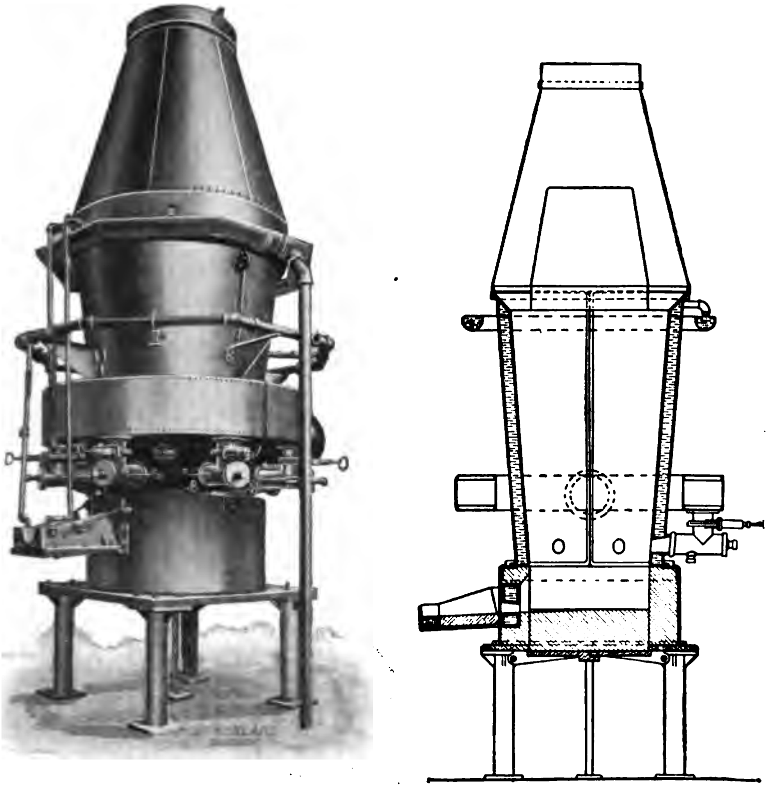


Fig. 32. Round Copper Blast Furnace in Full View and Section
Courtesy of Colorado Iron Works, Denver, Colorado

enough has accumulated to tap out into slabs or bars; the slag likewise is tapped intermittently from a level slightly above the metal tap. The gases will go to waste directly, or after simple elimination of the coarser dust.

Where Used. This type of smelting is apt to be found on frontiers where the surface ores are awaiting this easy treatment. The process had a very noteworthy run on the surface ores in Arizona

before the enormous development of the deeper sulphide ores which are being mined today. A furnace doing this identical work can be seen in operation almost any day in the city of Chicago.

The most remarkable case of oxide smelting in blast furnaces is to be found at Katanga, in Central Africa. Huge rectangular furnaces made in the United States are run there by United States men on the largest oxide deposits (excepting the sulphates of Chili) which always have come within the range of blast furnaces.

An oxide blast furnace necessarily is limited by the generally meager extent of such ores; from the fact that it is difficult to make clean slags economically, small mines will prefer to turn over their ores to large sulphide smelteries where they can be treated equally well with the regular sulphide ores.

Sulphide Copper Smelting

Strong-Reduction Type. *Conditions of Operation.* The smelting of coarse sulphide of copper ores is a type of reduction which has developed in different chemical aspects, as well as in furnace capacity. As indicated in the outline, some occasions have required the development of a smelting which much resembles the strongly reducing conditions of lead and iron smelting. This is to conserve the sulphur and to assemble all of the copper in a matte or artificially enriched sulphide compound of iron and copper. Sulphur and copper have a remarkable affinity for each other, and, with conditions at all reducing, they will go through the furnace unchanged and come out together as matte for further treatment to make blister copper.

Usage. A few occurrences of this type of smelting have been found noteworthy but there is little use for the process at the present time. The most conspicuous example is at Mansfield in Germany.

Matting Furnace. *Construction.* Fig. 33 shows a copper-sulphide furnace which illustrates well the features as now in use in this very important method of copper reduction. The crucible is made very shallow and is set on jacks so that the bottom of the furnace not only is kept cool but is removable easily. The smelting zone is water-jacketed thoroughly and, from the picture, it is seen that not only is the breast well water cooled but the matte spout is likewise. The tuyères are arranged closely together along

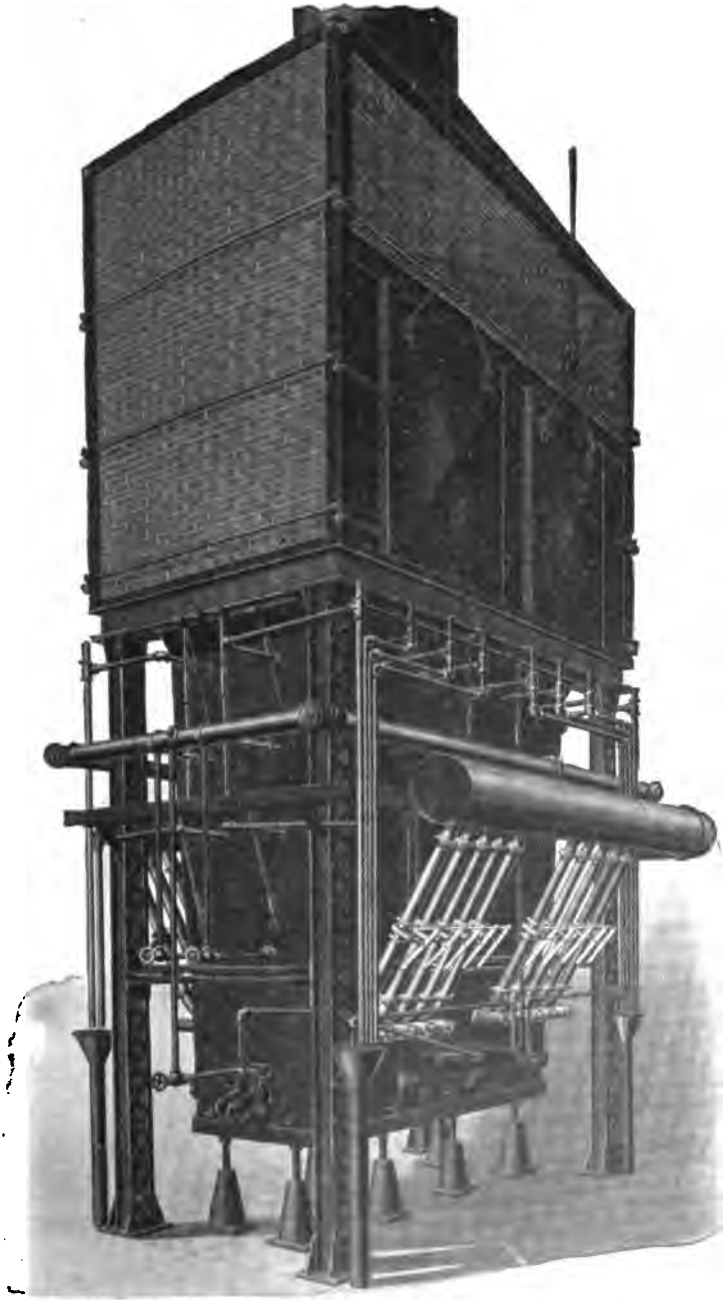


Fig. 33. Water-Jacketed Blast Furnace for Smelting Copper Ores
Courtesy of Allis-Chalmers Company, Milwaukee, Wisconsin

both sides of the furnace, and it will be observed from the picture that the water overflow from each jacket comes out to the drain pipe entirely exposed so that the attendant can see always exactly how much water is going through any single section. The top of the furnace, which of course will be above the feed floor as the furnace is arranged in the building, is made of brick, and the gases leave through a large steel flue. The opening at the side allows of charging the full length of the furnace.

Operation. Sulphide furnaces of course are all charged mechanically, the cars usually dumping the material in along the side of the furnace. A further consequence of the large tonnage is that slag and matte are run off continuously into a forehearth or settle where the separation of matte and slag takes place. We know that in connection with oxide-copper furnaces internal crucibles are necessary, because of the easy chilling of metallic copper; with matting furnaces, however, the fiery matte is just as apt to cause trouble by eating through its container, and preferably is gotten out of the furnace as quickly as possible. From the matte settler the slag will be run off as overflow into slag pots, while the matte will be tapped out from a lower level and taken to the converters.

Semipyritic Type. *Characteristics.* Semipyritic smelting is so called because, to a certain extent, the sulphur in the ore is utilized as fuel; this means that the coke in the charge can be kept much lower than in a real reducing fusion. It depends on the fact that the copper will go with what sulphur is left, even though a portion of the sulphur is burned out by the blast. Furnaces operating on such a basis commonly have a very large volume of air blown in and there is no necessity for a high ore column, the flames often playing entirely through the charge.

Importance. In the semipyritic type of sulphide reduction, there is the greatest development of sulphide copper smelting. This constitutes a very great use for the blast furnace, and at one plant smelting lump copper ores in this way we have the largest blast furnace ever constructed, which will treat some 3,000 tons of charge in 24 hours.

Semipyritic smelting is the great blast-furnace process in the western States and likely will continue long to be so, in so far as lump sulphide-copper ore is available. It used to be of relatively

more importance before the development of reverberatories. The blowing of fine particles of the charge out of the furnace to make flue dust

Fig. 34. Copper Smeltery at Cananea, Mexico
Courtesy of the "Mining World"

always was troublesome and now is taken care of entirely by smelting concentrates and fine materials in reverberatory furnaces.

Typical Plants. A large plant for this sort of smelting, with all the supplementary facilities for handling the ores, flue dust, fumes, and gases, the converting of the matte, and the necessary power production, constitutes quite a metallurgical community. Such plants are situated at Anaconda, and Great Falls, Montana; Garfield, Utah; Kennett, California; Clarksdale and Douglas, Arizona; and Cananea, Mexico.

A typical one is seen in the illustration, Fig. 34, which shows the Cananea smeltery from the hills above the plant. From a distance the conspicuous objects are the ore bins, and bedding plant, the mills, the huge stacks, the enormous flues, and the multitudinous buildings, each for a specific operation in the plant.

Pyritic Type. *Process.* Pyritic smelting utilizes the sulphur in the ore as almost the entire source for the smelting operation. It is found that with a sulphide ore and siliceous gangue there is available from the burning of the sulphur and from the formation of ferrosilicate just about enough heat to accomplish the smelting operation successfully. On account of this close heat margin it is seldom attempted to run without a slight addition of coke, although such has been done when occasion demanded it. Other than in the use of this internal fuel, the chemistry of the process is exactly the same as in any sulphide smelting. Matte of course is the product of the fusion.

Usage. Small plants have been operated on this principle in Montana, and at Leadville, Colorado, but the greatest plant for this type of smelting has been and still is in operation at Mt. Lyell, Tasmania.

Roasting Copper Ores

Field. With the exploitation of the low-grade porphyry and copper mines of the western States and the production of enormous quantities of fine sulphide-copper concentrates, the mechanical multihearth roasting furnace has found a wide field of application. The outlet for these concentrates is by means of reverberatory smelting, and their sulphur content first must be lowered considerably in order to bring the concentration of the copper in the matte high enough for Bessemerizing in converters.

Mechanical Roaster. The mechanical roaster for this fine sulphide ore has several hearths; the ore is fed in at the top, dry, and

most of the sulphur is burned out by the current of air over the hearths as the ore descends from one to the other on being worked across each hearth by the rabbles. The calcines preferably will be trammed hot to the reverberatory.

Stage of Perfection. There are several excellent mechanical roasters on the market, differing somewhat in manner of drying the ore, in the construction of the hearths, in the means for cooling

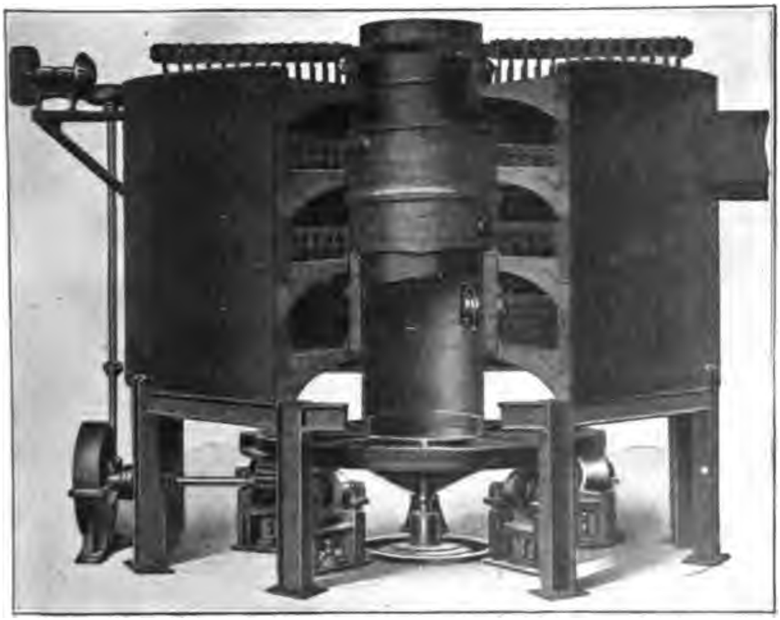


Fig. 35. Multihearth Mechanical Roasting Furnace
Courtesy of Wedge Mechanical Furnace Company

and rotating the rabble arms, and in the facilities for admitting the air to carry out the oxidation.

Mechanical roasters of the general type illustrated in Fig. 35 have been brought to a stage of very high tonnage production and of extremely cheap treatment cost per ton. Furnaces are run to treat as much as 100 tons in 24 hours on one set of 20-foot hearths, while the total cost of operation will probably be less than 25 cents a ton. The perfection of this type of furnace has strengthened the development and stability of reverberatory smelting enormously.

Reverberatory Copper Smelting

Present Development. Copper reverberatory smelting, in its most essential features as practiced today, is one of the most interesting technical developments of the generation; from little furnaces treating hardly more than 20 or 30 tons a day in 1880, their size has grown until now they are built 25 feet wide and 140 feet long, and will smelt up to 800 tons in 24 hours.

The most remarkable advance has been in fuel economy and in general furnace efficiency. Particularly, it has come to be appreciated that the secret of rapid smelting is a sufficient excess of hearth temperature over the formation temperature of the slag. From the old coal-burning fire box there has been developed gradually the use of gas, oil, and powdered coal as far superior means of producing the enormously long flame required to heat the furnace properly.

In the mechanical construction of the furnace, reverberatories have been greatly improved, while the physical structure is now made of a size which a very few years ago could have been proven impossible.

Reverberatory Furnace. The copper reverberatory is essentially a huge heated receptacle in which the charge is melted down. It is on this basis that its attainments have been so remarkable. The furnace is depended upon now to oxidize considerable of the sulphur of the charge, while the matte and slag produced hardly differ from those produced in the copper blast furnace.

Typical Features. The general proportions of a modern reverberatory furnace fired with pulverized coal are seen in Fig. 36. The furnace is essentially an extremely long but rather broad and thin melting box. From the burners at the firing end the hottest part of the flame spreads out and covers the bath up to the section where the roof is lowered; the picture indicates that this is about at that point where the matte is tapped off. Immediately above this hottest section are the hoppers for letting in the charge. The charge has a long way to travel and abundant opportunity to separate into matte and slag before it reaches the skimming door situated at the opposite end. Slag will be skimmed near the end farthest from the burners, while the matte commonly is tapped off at about one-third of the total distance from the burners, and is sluiced directly into

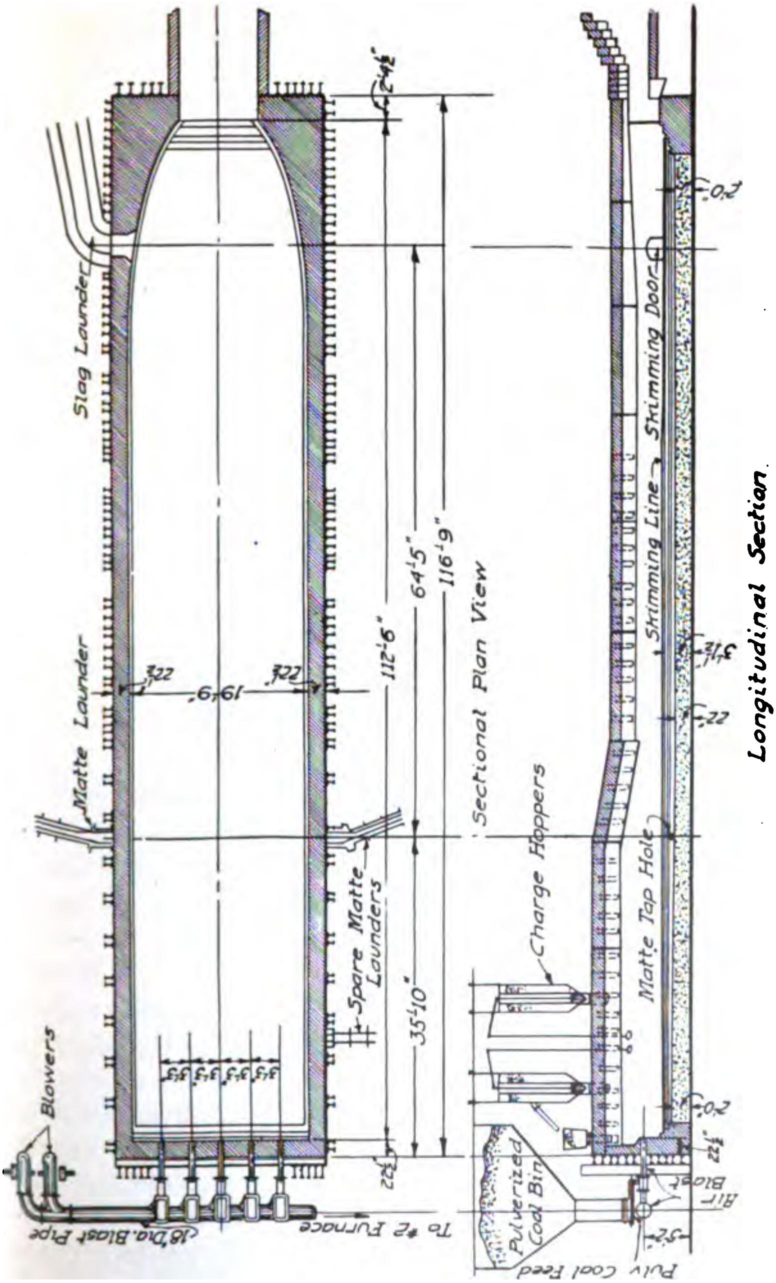


Fig. 36. Plan and Section of Copper Reverberatory Furnace
Courtesy of American Institute of Mining Engineers

the converters, or is handled in ladles. It is noticed that the furnace is built massively and is held together thoroughly with a great number of steel I-beams placed entirely about the furnace walls.

Reverberatories usually are equipped with waste-heat boilers for recovering as much heat as possible from the exit gases.

Converting Copper Matte

Converter. *Lining.* Copper matte produced either in blast furnaces or in reverberatories is poured into large receptacles to be blown to what is known as *blister copper.* A few years ago these

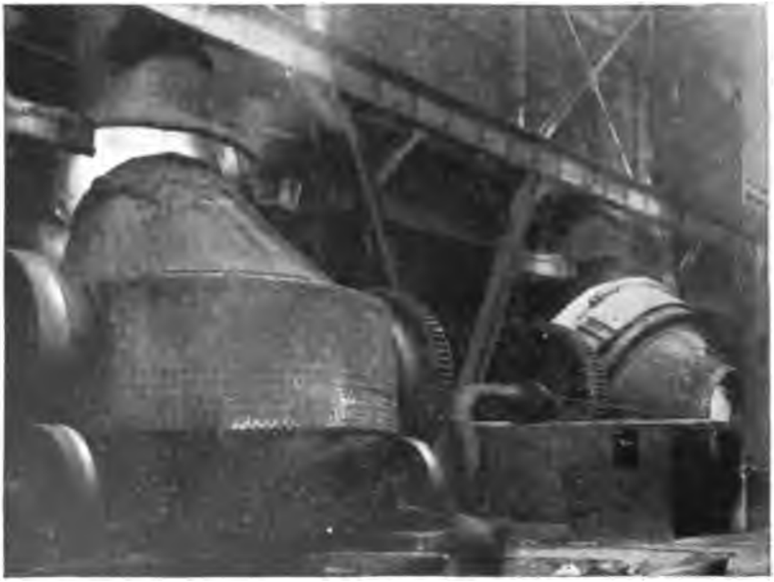


Fig. 37. View of Two of the Great Falls Converters at Anaconda

steel-bound receptacles were lined exclusively with siliceous material, and, in burning out the sulphur and the iron from the matte, this siliceous material was depended upon for making slag with the iron oxide produced. Metallurgists recognized the disadvantage of this consumption of the lining of the furnace and of the frequent renewals, and it is due to the efforts of two eminent metallurgists, Smith and Pearce, that, in 1904, converting was accomplished successfully in converters lined with basic material which would withstand indefinite operation.

We now are able to maintain the integrity of a converter lining for many months. The siliceous material required for the formation of the iron slag is added as necessary during the conversion of the matte to metal.

Operation. The size of the converters has increased continuously until they now are built 20 feet or so across. These enormous barrel- or pear-shaped steel monsters are tipped back and forth by hydraulic or electric power for charging, blowing, and pouring. A picture of some of these largest pear-shaped converters is seen in Fig. 37. The nearest one is upright and the matte is being blown as is seen by the light at the mouth of the converter. The second converter apparently is red hot inside and may be just pouring the metal or may be in some other stage of the process which requires tipping over so that the contents will run out. As the converter is in this position, the tuyères and the air box are fully exposed high in the air; when tipped back in blowing position, they evidently are so placed that the air will squirt through the bath of red-hot matte inside.

Chemical Principle. The principle of the chemical change in the converter is that, when air is blown through the metal, the sulphur and iron are oxidized and practically are removed before the copper itself is attacked. Some of the sulphur and all of the iron will be oxidized to leave what is known as *white metal,* a practically pure sulphide of copper, after which the blowing will be continued until this all is changed to metal by the complete elimination of the sulphur as sulphur dioxide.

Usage. Converters are a necessary accessory in all large sulphide smelting establishments, and change the matte into metal at a cost of a small fraction of a cent per pound.

REFINING COPPER METAL

Furnace Method

Practical Necessity. The great bulk of copper as produced in converters and as turned out is by no means pure enough for refining by electricity; in fact the electrolytic refining of copper is possible commercially only when the metal to be refined already is of very high copper content. Because of this, if the blister copper is not melted in a reverberatory at the smelting plant, it necessarily is

done at the copper refinery, which may be located at some point better situated for the obtaining of cheap power—the most essential feature of electrolytic refining.

The furnace refining of nearly pure copper is, then, an essential step in the production of merchantable material. It is carried out extensively at all copper refineries, both on blister copper and on the cathodes produced by electrolytic refining. The different sorts of blister copper are susceptible to extensive furnace refining, but the melted cathodes require it in slight degree only and that largely for the exact regulation of the final oxygen content of the metal.

Partial Separation of Metals. Furnace refining can almost completely remove iron, lead, tin, sulphur, manganese, and zinc; arsenic and antimony are partly removed by this refining, but it will have little affect on selenium, tellurium, bismuth, or the precious metals. This accounts for the fact that furnace refining is an essential operation, yet is unable to produce a commercially pure copper as demanded in the trade.

Process. *Oxidation.* This furnace refining of copper consists in melting down the copper in a large coal-fire reverberatory, during which melting considerable of the impurities will be oxidized and floated on the surface of the metal. More extensive oxidation can be effected by flapping the metal with iron paddles or by blowing in air through iron pipes. This process of oxidation, however, introduces undue amounts of oxygen, which is absorbed by the metal and retained in solution. The oxidized slag having been removed, the excess of oxygen then can be taken out of the metal by covering with charcoal and thrusting in logs of wood, which, decomposing in the hot bath, use up and remove the oxygen.

Electrolytic Method

Usage. Nearly all crude copper is electrolytically refined; this means that after the metal has been smelted to black copper, blister copper, or any sort of crude cakes, they are remelted and somewhat purified in an anode melting furnace and cast into anodes. The anodes are refined in the electrolytic cells and the cathodes melted, before their final exit from the refinery as ingots, slabs, and wire bars.

This type of refining is applied to most of the metal won by the

reducing methods referred to previously—the main exception is some of the Lake Superior copper which is refined in the smelting furnaces, as it was originally quite pure.

Complete Separation Effected. From a reasonably pure anode, as results from the remelting of blister copper in the refining furnace, electrolytic refining is able to produce a metal of the most extreme purity, except in that particular element, oxygen, which again will be introduced in the final remelting as will be necessary to make shapes, ingots, slabs, and wire bars.

The trade demands at the present time are extremely exacting, and most of the copper of commerce, therefore, is put through this process of electrolytic refining. Further than this, electrolytic refining effects an extraordinarily complete separation of the precious metals, the removal of which it is equally difficult to accomplish by any furnace process.

Process. *Arrangement of Electrodes.* Electrolytic refining consists of dissolving copper from an anode immersed in a strongly acid solution of copper sulphate, of forcing the electropositive particles of copper through the solution, and of plating them out on a sheet of pure copper suspended close to the anode; the particles coming out on this near-hanging strip of copper will constitute the cathode; the force accomplishing this transfer is of course the electricity which is supplied to these thousands of couples in great quantity by the generating system in the refinery. It is common to hang about twenty of these couples in an acid-proof tank, which is about 3 feet wide, 4 feet deep, and 10 feet long. The electric current is sent through each tank, with the respective anodes and cathodes arranged in parallel. A number of tanks will be put in series and arranged in groups to accomodate the amperage and voltage most suitable as generated by the large dynamo units.

Action of Electrolyte. The electrolyte is kept at a very definite concentration of copper and free acid and is maintained in active circulation through the vats at a constant temperature of between 60° and 70° C. The electrolytes of different plants average close to 4 per cent of copper and 12 per cent of free acid. Anodes waste away rapidly due to the solution of the copper and in about a month's time are taken out and new ones substituted. The cathodes are taken out more frequently, when the freshly deposited copper

is stripped from the starting sheets, and the sheets are put back again for a new layer.

The anodes which are taken out of the vats are washed to remove the slime and then are remelted into full-sized anodes to be

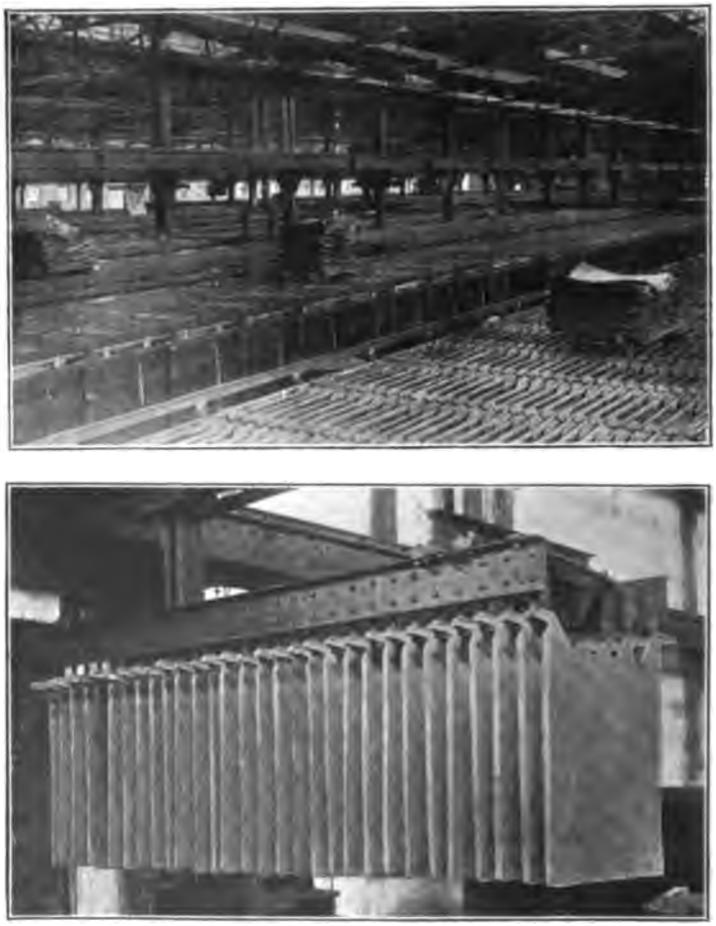


Fig. 38. Electrolytic Vats and Anodes
Courtesy of "Engineering and Mining Journal"

put again into the tanks. Fig. 38 indicates a series of these anodes as lifted out from one of the tanks, which are seen together in the other view thickly packed on the floor of the large electrolyzing room.

Separation of Doré Metal. A large quantity of sediment collects in the bottom of the electrolyzing vats and is washed off from the

anodes when they are cleaned. This mud is carefully removed from the vats and collected by itself in large tanks for further treatment. It contains the impurities originally present in the anode, of which the most important are gold, silver, palladium, and platinum. Selenium and tellurium also are undesirable components of this mud. This mud is washed, its copper content largely depleted with a sulphuric-acid treatment, the selenium and tellurium oxidized away in a small reverberatory, and a metal known as *doré metal*

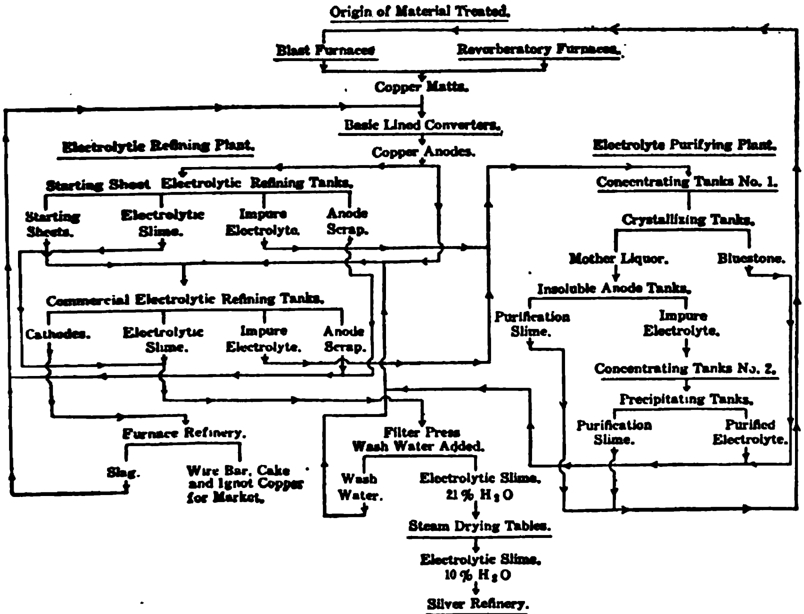


Fig. 39. Flow Sheet of Copper Refinery
Courtesy of American Institute of Mining Engineers

finally obtained which goes to the silver refinery for separation and recovery of the gold, silver, palladium, and platinum.

Diagrammatic Summary. Fig. 39 may be studied to advantage as a summary of the course of materials and processes in a refinery. It is necessary that the diagram take up the material as produced by blast furnaces or reverberatory furnaces and that it turn out market copper or partly dried slimes to go to the silver refinery. The main electrolytic treatment for the bulk of the material is on the left-hand side of the diagram; the right-hand side is devoted

to the course pursued in purifying the electrolyte, a small portion of which is being separated continuously and treated to get out the accumulating impurities. This diagram may be studied in every detail to much advantage.

SILVER REFINERY FOR A COPPER PLANT

Supplementary Treatment. There are only a few copper refineries to work up the entire tonnage of the metal produced in this country; the amount of precious metals found in the blister copper is considerable, and it therefore results that there is a good deal of material to be separated and provided for in a silver refinery.

The doré metal which is obtained from the preliminary fusions just mentioned is cast at those same furnaces into anode shapes and electrolyzed in nitrate-acid solution to obtain a deposit of remarkably pure silver on the cathode. The silver thus obtained will be merely remelted in large crucibles and cast into bars for market. From the electrolysis of these anodes a residue results which contains all the gold, palladium, and platinum originally present in the copper ore. These metals will be assembled and separated by either wet or electrochemical means to be cast finally into bars of pure gold, palladium, and platinum.

Importance. The silver department of a copper refinery thus is quite extensive in its scope and really handles a surprising amount in money value. As several of our largest companies operate both lead and copper refineries, it is common to draw the doré metal from the different refineries together in this same department; thus the American Smelting & Refining Company at its plant at Maurer, New Jersey, gets the precious metals from various plants and operates the largest silver refinery in the world.

LEAD

LEAD—SILVER SMELTING

Relative Importance. The smelting of lead is one of the important metallurgical industries of the United States, and we are able to produce considerably more lead than any other single country. Workable deposits of lead ores are found throughout many western States, as well as in Wisconsin and in Missouri.

But, although the lead-smelting industry itself is of very considerable magnitude, its importance is still further enhanced because lead is used extensively as a collector for precious metals. By this, we mean that many gold and silver ores are used as fluxes in lead smelting, or even may be put thus into the lead smelting charge for the sole purpose of recovering their gold and silver contents along with the lead.

Recovery of Precious Metals. It is common to work up secondary precious metals by smelting industrial residues with leady materials at industrial centers, like Chicago and New York. Some western plants likewise are virtually gold and silver smelters. A large part of the tonnage smelting may have its main value in the precious metals, and barely enough lead is put in the charge to carry out the function properly in a lead blast furnace; that is, enough bullion to keep the crucible in good running order.

It has been described how the precious metals accompany copper throughout the winning of that metal, and in the same way the precious metals go through all the processes in the recovery of metallic lead and finally are separated in the pure state. Thus, in studying the metallurgy of copper and lead, we cover a large section relating to the winning of gold and silver.

Lead Minerals. The lead minerals occur as follows:

Galena. The universal lead mineral is galena, PbS, which occurs as the main one of all our deposits.

Lead Carbonate. The carbonate, $PbCO_3$, is a surface mineral commonly found as an oxidized ore over deeper deposits of original sulphides.

Lead Sulphate. The sulphate, $PbSO_4$, is another oxidized mineral and may accompany lead ores in general to a slight extent.

Lead Silicate. The silicate, Pb_2SiO_4, possibly is a more important lead mineral and sometimes constitutes a rather important ingredient in the ores of certain mines.

Lead Oxide. The oxide, PbO, mixed with other metallic oxides may be found in some surface deposits.

All of the surface oxidized ores are reduced very easily in the simplest way and are used up only too quickly whenever the mines are vigorously exploited. Digging deeper into the ground, the miner most always begins to produce a larger and larger per cent of his

material as sulphides which possibly are concentrated from a rather lean original ore. Thus the lead smelter is confronted in general with higher sulphur ores and finer materials.

LEAD ORE REDUCTION

Reverberatories. Considerable pioneer work has been done both in this country and in Europe to develop lead smelting in reverberatory furnaces, but the process is now about extinct; If it

Fig. 40. Men Working at Lead Ore Hearth

is attempted to smelt galena in a reverberatory, there first must be a roasting or oxidizing interval before the main reduction can be accomplished. The process, therefore, is out of line with reverberatory development so successfully evolved in the one-reaction processes with other metals.

Hearth Smelting. The ore hearth is an ancient appliance somewhat modified by later improvements. It consists of a basin to hold the melted lead and to support the charge to be smelted.

Sides restrain the fire while air is blown in from the back through holes which are placed above the level of the lead but under the surface of the charge.

Fig. 40 shows this accurately. A kettle for the smelted lead, a car for the residue, and hoods and a pipe to lead away the smoke about complete the equipment. In the picture the men are shown in front of the fire spreading out the charge and stirring it over and over, as must be done unceasingly.

Characteristics. The ore hearth has the advantage of requiring no mechanical accessories besides the blower; it is started and stopped at a moment's notice and has an output depending only on the supply of ore and labor.

The great disadvantages of hearth smelting are that only a portion of the lead is recovered directly, while the remainder partly divides between the gray slag, the flue dust, and the lead fume which is produced in excessive quantities. Working up these latter materials requires blast-furnace smelting which thus has to constitute a part of the plant after all.

The ore hearth may be considered as a furnace in which considerable lead is recovered and the remainder of the charge is left in a roasted condition ready for normal blast furnace smelting; In this sense hearth smelting is treatment preparatory to blast furnace smelting.

Pot Roasting. Roasting was accomplished for many years in long hearth reverberatories by hand stirring of the charge (see Fig. 11). During the 90's a new sort of roasting was introduced from abroad where it had arisen, which consisted in blowing air through an ignited charge to both roast and sinter at the same time; the process was developed by Huntington and Heberlein and was called *pot roasting* for short. Within the last dozen years an improvement of this method rapidly has replaced [all the older ones in many plants.

Roast-Sintering. Down-draft roast-sintering is a truly remarkable process for desulphurizing and sintering lead ores preparatory to blast-furnace reduction. The charge is made up with the idea of having just enough metallic sulphides present to support a progressive combustion and to agglomerate the material fully. Fig. 13 is to be studied in detail again, while Fig. 41 is a side view of the same machine in action.

Operation. At the very left of the picture and at the top is seen the feed hopper which is fed with a conveyor with the well-mixed and moist charge. As the line of pallets, each carrying 3 grates, moves under this hopper it becomes burdened with a layer of charge and passes next under the small oil burner. From the burner the grates slowly move toward the right over the suction box, seen between the upper and lower lines of pallets, while the fire eats its way down through the cake and should be through by the time the

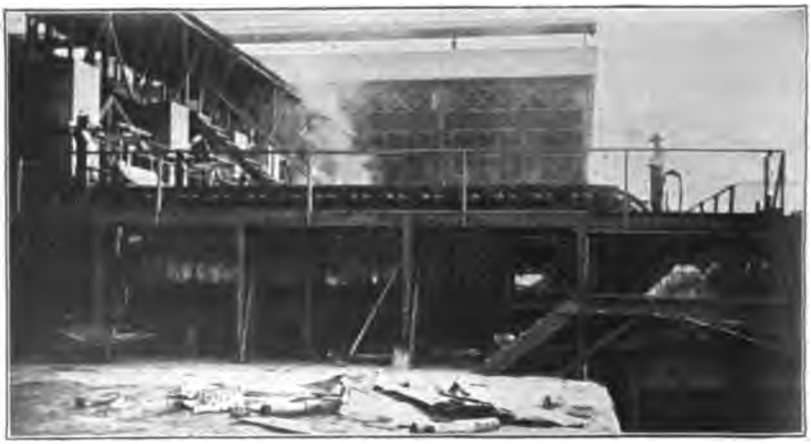


Fig. 41. Side View of Continuous Roast-Sintering Machine

material has passed over the box and is to be dumped off into the car which is in waiting.

The grates pass around the sprocket wheel at the discharge end and return under the suction box to come up again for a fresh layer of charge in passing under the feed hopper. The roast-sintering process is striking in its simplicity and is highly satisfactory as to the results obtained.

Lead Blast-Furnace Smelting

Importance. Aside from the lead made in ore hearths all our lead is now won in blast furnaces. This makes blast-furnace smelting of lead ores an extremely important topic.

The lead blast-furnace plant has its departments for sampling the materials, for storage of everything, for sintering, for power,

repairs, and means to settle flue dust and to cool and filter the gases. American plants usually dross the lead in 30- to 50-ton kettles, and then send it to the refinery.

Furnace Features and Operation. Both round and rectangular furnaces are common, the latter being customary in large plants. The peculiar features developed in America have been the siphon tap for the lead, full water-jacketing of the fusion zone, patent tuyères, and mechanical feeding. Fig. 42 is an excellent picture of a round furnace in an European plant as partly improved with siphon tap, and partly water cooling.

At the base of the furnace is the steel-bound crucible and the enlargement on the side which constitutes the lead well out of which the lead is pouring into the small kettle. The circular shape of the entire shaft may be seen plainly; the cast-iron posts support the bustle pipe and the steel shell of the top. This furnace appears to be water cooled only about the breast and the tuyères. The slag tap is on the right-hand side of the furnace, while the lead which runs out the well is ladled into the molds seen in a row in the immediate foreground.

In the lead blast furnace the strength of reduction is not nearly so great as in the iron blast furnace; the temperature in the smelting zone is not nearly so high, and the fuel required on the charge is several times less. A calcium-iron silicate slag always is made; a little matte always is formed to settle out in the forehearth or the pot settler below the slag. This matte carries the copper of the charge, as well as lead and values, and so is separated carefully and worked over for its metals.

Bag Houses. Flue dust is recovered in large brick or steel chambers and ducts, the latter made long enough so that the gases will be cool enough to enter safely the cotton or woolen bags at the bag house. All United States lead plants have bag houses.

Characteristics. Bag houses are wooden, iron, or brick structures surrounding enough long porous bags to filter the solid particles from whatever gas may have to be treated. The cellar compartments receive the fume-laden gases and the collected lead fume falls down into the same cellar whenever the bags above are shaken. The top of the cellar is the floor of the bag room; this floor is hardly more than a support for row upon row of iron thimbles about which

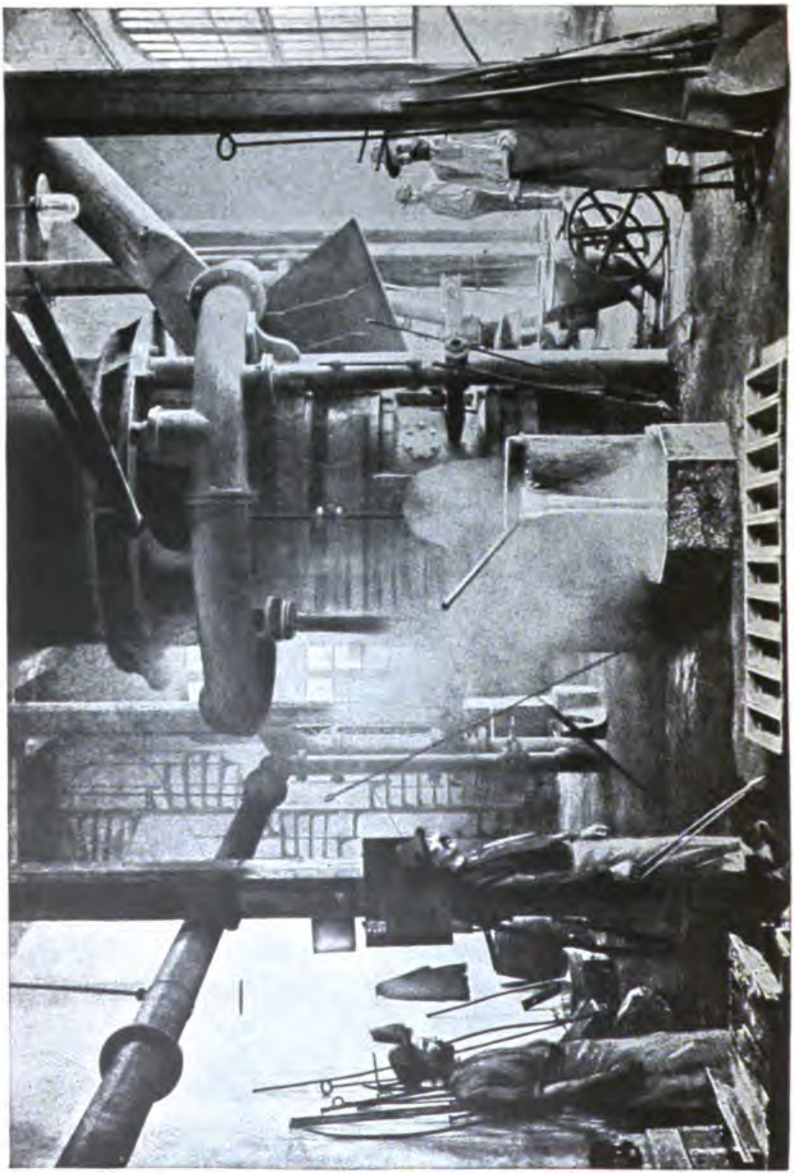


Fig. 42. Tapping Lead from Blast Furnace
Courtesy of Royal Austrian Commission

the bottom ends of the bags may be tied. The main chamber of the bag house is hung thickly with bags 30 feet long and 18 inches in diameter, which bags may be of cotton or of woolen fabric. Such a bag room may contain from 100 to 1,000, or more, bags; large plants commonly put partitions through so that one section may be repaired or cleaned while the others carry the load.

Fig. 43 indicates crudely something of the nature of this accessory. More often the structures have stacks instead of the opening along the roof as indicated. Bags may be shaken by hand, by mechanical means, and by reversing the draft with an auxiliary fan. The frequency of shaking may be once a day or every few hours.

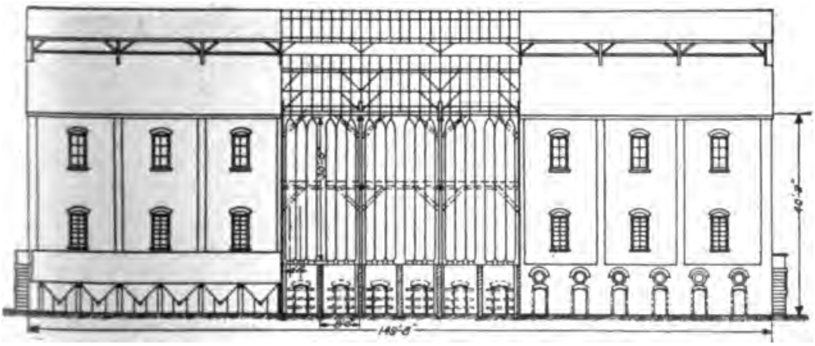


Fig. 43. Diagram of Bag House
Courtesy of American Institute of Mining Engineers

Status. The bag house is firmly established as an integral part of all lead smelting plants, both small and large, and is justified fully from the financial point of view as well as by being necessary from the hygienic point of view.

METHODS OF REFINING LEAD

Electrolyzing. Lead is now refined in four large plants by electrolyzing in fluosilicate solution. The main advantage is the recovery of bismuth, but, even with the recovery of bismuth, it is questionable if it is the more economical process. Parkes' process is the method commonly used.

Parkes' Process

Principle. Parkes' process depends on the fact that, if zinc is dissolved in molten precious-metal bearing lead and the mass is

allowed to cool, the crystals first separating carry nearly all the noble metals together with much zinc and lead.

Operation. *Separation of Metals.* The process is executed by melting the lead in large kettles and by heating with zinc to about 1 per cent of the weight of the lead until the zinc, which has a little higher melting point, is dissolved. The lead is cooled slowly, and the

Fig. 44. Faber du Faur Tilting Furnace

crystals which eventually begin to form throughout the mass are skimmed off and placed to one side. This is continued until the lead begins to chill as a mass. The lead is heated again and the process is repeated. After the second skimming the lead is heated and run out into refining furnaces where the dissolved zinc, 0.65 per cent, is eliminated by standing in the hot furnace or by blowing

air or steam through. The lead then is run out and is molded into 100-pound bars for the market lead of commerce.

Practical Requirements. There are, of course, many details that cannot be enumerated here; it ought to be said that the lead as it comes from the blast furnace usually requires a preliminary oxida-

Fig. 45. English Cupellation Furnace

tion, or softening, to get rid of all its dissolved copper and antimony; the zinc must be stirred most thoroughly into the molten lead, usually by mechanical means; the crusts are best squeezed to rid of as much lead as possible; the molding may be by hand, by siphoning off into a circle of molds with a movable trough, or by pouring several molds at once on a conveyor.

Retorting Furnace. The zinc crust which is removed from the desilverizing kettles is taken to a retorting furnace like that shown in Fig. 44. It is called a Faber du Faur tilting furnace; inside is a retort which is heated by the oil burner seen at the side near the bottom. The zinc is distilled off and collects in the condenser which is luted on in front. This condenser on front is nothing more than a retort which has become unsafe to use further for holding the heavy charge inside. It is seen that the furnace is mounted on trunnions so that the rich lead can be poured out after the zinc has been eliminated. The zinc is volatilized from the retort and condenses in the outside receiver from which it is tapped at intervals into the cast-iron mold seen ready on the carriage.

Cupellation. The rich lead from the retort next is taken to the cupel furnace in which the lead is eliminated and the precious metals are left by themselves as doré silver. The cupel furnace is operated as indicated by Fig. 45. It consists of a shallow oblong hearth in which is melted the rich lead; it is supported on wheels so as to be drawn out; it is adjustable so as to tilt up or down by the operation of the screw wheel seen in front; it is surrounded by brick walls with a good draft up the flue; from one side the flame from coal or gas plays over the metal while from behind a blast of air squirts onto the bath to oxidize the lead. The litharge formed by this oxidation floats to the front and dribbles over the breast to fall into the little pot in front of the man. The adjustment is kept so that only the very uppermost or surface layer—the newly formed litharge—can flow out; the metal is kept behind on the hearth. In this way the operation proceeds until all the lead has left the bath and only silver remains.

The final bullion left on the cupel hearth is the final concentration of all the precious metals originally in the ore. For electrolytic refining, it is taken to a silver refinery as described in the section under Copper; or, the silver may be dissolved out with sulphuric acid, the metal precipitated with copper, and, after collecting and drying, may be melted to fine silver.

ZINC

Ores of Zinc. *Occurrence.* The United States is especially favored in the matter of zinc ores and so is able to produce more of the metal than is any other nation. In New Jersey occurs the

mineral, willemite, which yields large quantities of an exceptionally pure metal. In Wisconsin and Missouri are the numerous mines whose ores smelted in the central States afford high-grade metal and make this the leading section of the country. Throughout the western States are many other mines, some of them enormously large, whose ores are mixed with minerals of other metals and which yield large tonnages but poorer quality stuff.

Mineral Forms. Zinc sulphide, ZnS, is the primitive mineral, but the carbonate, $ZnCO_3$, is quite an important mineral, and some silicate and some oxide come to light now and then. The carbonate may be calcined before smelting, although it usually is charged direct into the retorts. The sulphide must be roasted first before being available for reduction. If the ore is not well roasted, it causes serious loss; on this account zinc ores commonly are roasted far better than are either copper or lead ores.

ZINC ORE REDUCTION

Zinc Characteristics. The properties of zinc are such that the metal is not recoverable like iron, copper, and lead, which we have been studying. Zinc melts at 419.4° C. and boils at 940° C. Its reduction temperature is about 1050° C. *Zinc is reduced to metal above its boiling point.* Zinc vapor also decomposes carbon dioxide and at once reverts to zinc oxide. No blast furnace yet has been induced to produce the metal; it can be obtained only by reduction in small retorts with a large excess of carbon.

Two Types of Roasting Furnace. *Sulphur Dioxide Lost.* There are two chief types of furnace for roasting zinc ores. In the first type the flames which heat the ore play directly over the charge; the products of combustion and the sulphur dioxide from the roasting mix and pass up the flue together. All zinc furnaces are built with mechanical arrangements for stirring. In this first sort of furnace the ore and the flames enter at opposite ends; the ore gradually is worked to the fire end of the furnace under constant stirring. If 12 per cent is the amount of sulphur left in a mechanically roasted copper ore and 4 per cent is the amount in a roast-sintered lead charge, the permissible sulphur in a roasted zinc ore is more like 1 per cent.

Sulphurous Gases Separated. The second type of furnace lacks the innumerable variations found in the first class of furnaces.

They must keep the gases of combustion separate from the sulphurous gases, and the sulphurous gases are to be kept as concentrated as possible and used for sulphuric-acid manufacture. This second type of furnace is muffle built; there will be seven superimposed hearths with the three lower ones muffled so as to be heated with extraneous fuel. These furnaces have to be stirred mechanically, as do all zinc-roasting furnaces. The use of so many hearths, the muffling of the first three hearths, and the ducts for pre-heating the air and

Fig. 46. Block of Zinc Retorts in Action
Courtesy of "Mining and Scientific Press"

leading it into the furnace and for leading the gases out make a structure difficult to describe and even harder to draw.

Zinc Distillation Furnaces. *Retorts.* The retorts for holding the charge during zinc smelting are about 5 feet long, 10 inches in diameter, 1⅛ inch thick, and closed at one end. Several hundred such retorts will be placed nearly level in a long double furnace which is heated by gas, either natural or producer. It is now customary to have three or four rows of these retorts one above the other and as many as a thousand of them in one block. The retorts tip slightly downward so that they can be filled and cleaned easily.

Operation. The best practice pre-heats the gas and air in regenerators, and the gas is burned by letting in air at intervals in just

the right amount to furnish a uniform combustion the length of the furnace. Fig. 46 shows the external appearance of a large furnace in operation. The flame is seen playing from the end of each condenser as the monoxide escapes into the air. These furnaces will be charged only once a day, the smelting cycle completing itself in about 24 hours. Too high a temperature of course is not desirable because of its effect on the retorts; otherwise it is highly desirable to have a large excess temperature in the furnace to replace the heat absorbed by the reaction and to keep the reaction going lively.

The metal is graded and sold on specification, and refining is accomplished by redistillation; this latter is not done very often, as may be assumed.

CADMIUM

Usage. This is a very useful metal for low-melting alloys and for electroplating. Otherwise its uses are limited. No ores are known; it is recovered as a by-product from zinc smelting.

Fractional Smelting. Cadmium distills over at a temperature considerably lower than zinc does; it thus can be concentrated in the first metal vapors which come off during zinc smelting. This first enriched material is distilled two or three more times, when a nearly pure metal is furnished. Most of the cadmium of commerce is recovered by this fractional smelting of German ores. All the Missouri zinc ores are said to contain 0.5 per cent of cadmium on the average; this practically never is recovered in this country, and the price of the metal usually is something under a dollar a pound.

GOLD

RECOVERY OF GOLD

Methods. *Placer Mining.* Of the four main channels through which our supply is derived, the simplest and most ancient method for recovering gold is by washing sands and gravels which contain it in solid particles. This method is used in all parts of the world where gold occurs in loose material in sufficient quantity; it is called *placer mining.*

Milling and Amalgamation. If gold occurs in solid rock, as it does in many places, the rock must be crushed to free the gold which can be recovered by washing over copper plates amalgamated

with mercury to catch and retain the particles of gold as they are washed over. This type of recovery is called *milling and amalgamation.*

By-Products. We have already indicated that much gold is recovered in the smelting of copper and lead ores; such metal might be called *by-product* gold, for it is recovered incidentally in the working up of these other metals.

Cyaniding. Another highly important method for recovering gold wherever it occurs in minute particles, as it usually does in solid rock, is by treating the very finely crushed rock with a dilute solution of sodium cyanide or potassium cyanide. Fine gold is dissolved easily by such a solution, and the gold can be recovered by treating the solution with a more electropositive metal, such as zinc or aluminum, when the gold will be precipitated out and can be filtered off, dried, and melted into bullion.

Placer Mining

Variations. *Simple Equipment.* Placer mining can be carried out with the very simplest outfit, such as a gold pan, a rocker with riffles, or a sluice box whose bottom is suitably roughened to collect the heavy particles of gold which are inclined to stop wherever they can find lodgment. Mercury usually is sprinkled on during the operation to assist in the recovery by catching the particles of gold and by drawing them within the heavy globules of the extremely heavy liquid.

Hydraulicking. An extension of the simpler placer-mining idea is carried out by hydraulicking with water under pressure, so that loosely cemented gravel banks can be worked just the same as ordinary gravels.

Steam Thawing. Another extension is by thawing frozen gravels with steam points, so that the dirt can be subjected to common sluicing methods.

Dredging. A final refinement of placer mining is to use dredges to dig through whole banks of gravel whenever they occur under water. These dredges will float in rivers, lakes, or artificial ponds, as they dig up the gravel with continuous digging equipment at one end, wash the gravel on board the boat, and finally discharge the refuse at the other end to make new ground. Fig. 47 shows one of

Fig. 47. Large Gold Dredge at Work in California
Courtesy of General Electric Company, Schenectady, New York

these huge dredges at work. The digging ladder is at the right, the discharge behind at the left. The gold recovered will be put in shape on board to be handled by the United States mint.

Milling and Amalgamation

Process. *Improvements.* The simpler methods of milling rock by dropping stamps on the chunks and of recovering the gold by amalgamation has received much refinement in recent years. Other types of grinding machines, concentrating machines, and

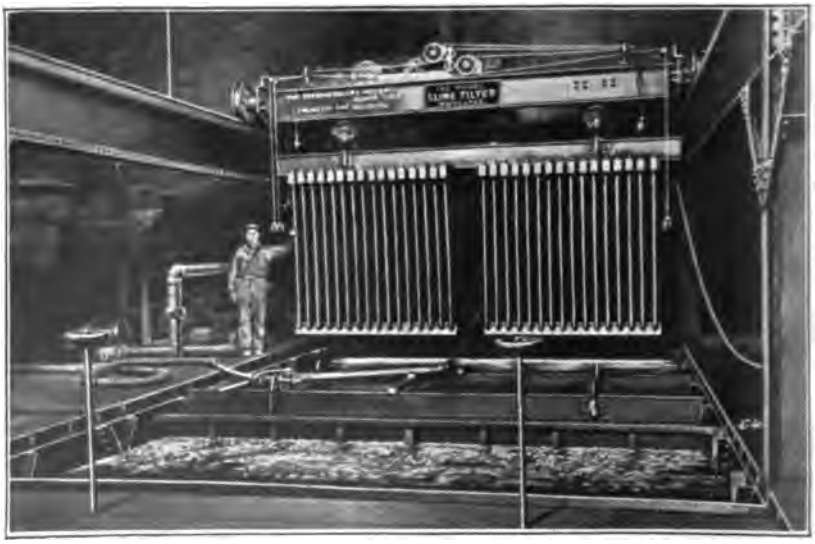


Fig. 48. Suction Filter for Cyanide Pulp—Movable Type
Courtesy of the Moore Filter Company

accessory apparatus have been introduced to advantage. Cyaniding accompanies amalgamation in some cases.

Cyaniding

Process. *Milling.* The full recovery of gold from a crushed ore usually demands very fine grinding. The plants have been meeting the requirements and now have tube and ball mills of continually improving duty.

Solution. If the cyanide solution has not been introduced in the grinding it will be added immediately after. Its best effect always is produced in the presence of enough aeration and agitation

to allow fully the reaction indicated in the following, which is the common equation for the chemistry of the process.

$$4Au+8KNC+O_2+2H_2O=4AuK(NC)_2+4KOH$$

Special tanks for this purpose have been devised which do the work quickly. Other chemicals may have to be added at this time, for any acidity is to be neutralized with lime, and some ores require further oxygen carriers.

Separation. When the gold finally is in solution, the solid matter of the pulp may be separated by decantation or by filtration; both operations are extensively used.

Fig. 48 indicates to what refinement the filtering devices have advanced. These huge filter leaves are immersed in the pulp, and the solution is sucked through until a cake has formed, after which the whole row of leaves is transferred to another tank for washing, then to another for discharge of the barren pulp.

The cyanide solution is run through zinc boxes, or is charged with zinc dust and then filter pressed; either of the processes gives the metal to be dried, melted with fluxes, and finally sent to the mint for parting.

Electrolytic Refining

Process. Electrolytic gold refining is used extensively in this country and abroad. The electrolyte is a hydrochloric-acid solution of gold chloride, and the transfer is made from anode to cathode, as in all such processes. This is by far the most precise method for separating gold from the other noble metals, which remain either as slimes or in solution.

Adaptability to Silver Recovery. This process is adapted to recovering silver, if certain modifications are introduced. We have already learned that silver is refined in exactly the same way. Thus, in describing copper and lead smelting, placer mining, and cyaniding, we have covered the metallurgy of silver as now practiced.

ALUMINUM

Commercial Recovery. Although aluminum is the element next most abundant to oxygen and silicon in the earth's crust, the recovery of the metal is a distinctively modern metallurgical feat.

For nearly 100 years aluminum has been known in the metallic state, but only since 1886 has the production of the metal been on such a scale that it has been of commercial use. The reason why we have not had aluminum before is because of the difficulty of freeing it from the oxygen with which it is so intimately associated in nature.

Aluminum is one of the most useful of the common metals, and with its application to a great variety of purposes, the necessary facilities for its production by low-cost electricity continually are being augmented.

Process of Reduction. We are able to reduce aluminum from a mixture of the double chlorides of aluminum and sodium by the use of metallic sodium at a red heat. If a mixture of chemically prepared anhydrous chlorides with cryolite—a sodium-aluminum fluoride—is mixed with metallic sodium and charged suddenly into a hot reverberatory furnace, the reduced aluminum finally can be tapped out of the furnace into ingots. This entire process is very expensive and probably is not used at the present time.

Hall Process. The Hall process is the one most extensively used. This process consists in electrolizing aluminum oxide in a molten bath of cryolite with large carbon anodes to supply the current. The carbon electrodes necessarily are oxidized by the oxygen freed from the reaction; the aluminum collects in a layer below the fused bath and is tapped out at intervals into molds.

Critical Details. The process for making aluminum is extremely simple but is operated only with much attention to many critical details. The electric current through the furnace must be exactly right to keep the bath molten, as well as to effect the electrolytic decomposition of the aluminum. Only since we have been able to make suitable carbon electrodes has the process been possible commercially. Another extremely important detail is the exact chemical composition of the bath, which must be lighter than the fused metal; the two substances are of almost the same density in the molten state, and, unless the fused salt is kept slightly less dense than the aluminum, the latter would float, and not only burn but, of course, would disrupt the process entirely.

NICKEL

Occurrence and Use. This metal very much resembles iron in its properties. Its far more extensive use is precluded by nothing less than the natural scarcity of its ores. A few deposits of silicate mineral are known in the United States, but it never has been possible to produce the metal from them at a price to compete with the cost of production from the sulphide deposits of Canada and New Caledonia.

The uses of the metal most interesting to the metallurgist are as a steel-alloying element, for electroplating, and as the chief component of a nickel-copper alloy known as *Monel metal.*

Nickel preserves its bright appearance remarkably well in ordinary air and therefore is used extensively as a coating or electroplate over more tarnishable metals. The electrolytic copper refineries produce some nickel from their electrolyte purifications which is available for this use.

Reduction. *Canadian Process.* The mining and early smelting processes, as carried out at the mines in Canada, are well known, but the companies attempt to suppress the later processes until we again see the metal and its alloys when ready for sale. At the mines in Canada the ores first are roasted, in the open or otherwise, then some type of blast smelting—blast furnace or converter—or, more recently, reverberatory smelting eliminates the gangue and produces a nickel-copper-iron matte. This is the end of the process as accomplished in Canada.

Mond English Process. The Mond process is supposed to be used by the company of that name in England; it depends on the fact that, by the use of carbon monoxide, the nickel can be volatilized and thus separated from the other metals.

Process in United States. The process in use in the United States presumably is that of separating the sulphides of the metals with sodium sulphide, the heavier nickel sulphide separating below the layer of the other mixed sulphides. After this separation the sulphide must be roasted to oxide and the oxide then reduced to metal. The metal thus produced is by no means pure; there is apparently no difficulty in producing a very pure metal by electrolysis of this crude metal, and such is on the market.

Monel Metal. Monel metal is the natural alloy produced by winning the metal from the nickel-copper matte without separation, presumably by roasting, and then by straight reduction with carbon. This alloy analyzes approximately Ni, 67 per cent; Cu, 27 per cent; Fe, 2 per cent; Mn, 3 per cent; and Si and C each 0.5 per cent. It is a strong, tenacious alloy, much like steel, but far more resistant to corrosion; because of the latter property it is finding much industrial application.

ANTIMONY, BISMUTH, MERCURY, TIN

Common Characteristics. These four metals are all reduced easily from their oxides without any difficulty at all. All four likewise are perfectly stable at ordinary temperatures, while, at higher temperatures, they do not decompose carbon dioxide and therefore can be won by simple reduction with carbon at a red heat. That they are such expensive metals follows from their relative scarcity in nature and not at all from the trouble of winning them from their ores. Their low melting points, ease of reduction, and moderate chemical activities make their winning a simple task for the metallurgist; when they occur in small quantities with other metals, it may be quite a different matter to separate and to recover them efficiently.

Antimony. Antimony is found chiefly as sulphide. This sulphide can be treated with metallic iron to yield metallic antimony directly. The operation can be carried out at moderate temperature in any suitable receptacle. The sulphide likewise can be roasted to oxide by the simplest means; the oxide then can be reduced to metal with carbon. Neither process offers particular metallurgical difficulty.

Considerable antimony always is recovered in lead refining; this is turned out as hard lead (12 to 14 per cent Sb) ready for use.

Antimony is used as metal chiefly in the minor alloys.

Bismuth. Bismuth occurs sometimes as metal, in which case it can be liquated from its gangue and recovered directly as metal. If an ore contains sulphide of bismuth, it can be roasted; this roasted ore as well as oxide ores are reducible directly to metal without difficulty, and they are reduced best in reverberatory furnaces.

Bismuth is recovered in electrolytic lead refining; in this case, any bismuth in the lead goes to the silver refinery in the tank slimes.

In the refinery it is separated from the silver by oxidizing fusions, is reduced to metal, and is refined electrolytically.

The metal goes into pharmaceutical preparations and into alloys with low melting points.

Mercury. Mercury occurs in ore deposits mainly as its sulphide, cinnabar. An oxidizing roast of this compound frees the metal which is condensed in suitable receptacles or chambers. The literature contains abundant accounts of the devices for accomplishing this end. The metallurgy of the process is simple and most excellent results are reported wherever there is ore to treat.

Tin. Tin occurs chiefly as oxide in nature. This oxide is very heavy, and the mineral can be concentrated to a product high in tin. Concentration is effected by panning, by dredging, and by crushing and mill treatment. The concentrated mineral is reduced to the metal in either shaft or reverberatory furnaces.

It is rather necessary to have the concentrates as clean as possible to prevent the reduction of the other metals which might accompany. The furnaces used are all small, and the tin on the market is of surprisingly good grade. Tin is difficult to remove from other metals when it accompanies them, which, fortunately, is seldom suspected.

TUNGSTEN

Occurrence. This metal occurs sparingly in nature as tungstate of calcium, of iron, and of manganese. The minerals are conspicuous on account of their high specific gravity.

Reduction. *Metal.* The concentrated mineral is fused with sodium carbonate which forms the soluble sodium tungstate and allows the removal of the other metals by filtration. From this solution acids precipitate the oxide of tungsten, WO_3. This oxide is reducible to the metal directly.

Ferro-Alloys. For the production of the ferro-alloys the oxide will be reduced along with some iron to act as carrier. This is the way it is put into steel. Ferrotungsten as reduced with iron in the electric furnace commonly runs over 70 per cent tungsten. There is a very great demand for the tungsten steels and their price often is well above a dollar a pound.

Modern Ductile Form. But tungsten can be reduced to metal more pure than this, when it appears as a gray powder without

displaying any sign of malleability or ductility. A few years ago the research laboratory of a great industrial company learned how to make this metal in ductile form. The more it was heated and worked, the stronger and softer it became. Thus was discovered the strongest, most dense, and highest fusing metal we have. Its uses have developed in other fields, although it is used more than ever for filaments in incandescent-light bulbs. The strength of tungsten wires exceeds even the strength of the strongest steel wires.

The one great restraint on many uses for such a metal is that, although its melting point is about 3000° C., yet this heating must be done with exclusion of air, lest the metal burn up with a flash.

SODIUM

Reduction Process. Metallic sodium can be produced by several of the most energetic straight chemical reductions at very high temperatures, but the electrolysis of its fused hydroxide has proved cheaper than any other method, and that is the process used exclusively today.

Electrolysis. The anhydrous hydroxide fuses at about 300° C.; if the molten substance is subjected to electrolysis just above this temperature, sodium and hydrogen will be liberated in chemical equivalents atthe cathode, and the corresponding amount of oxygen at the anode. The operation is carried out in small pots holding about 250 pounds of the caustic. Through such a bath, suitably provided with anode and cathode and with means to keep the gases separate, some 1,200 amperes at 5 volts will be sent. The liquid sodium collects in a receptacle at the top of the bath and is dipped out.

Usage. If sodium chloride could be used instead of the hydroxide, the metal would be much cheaper; such a process has not been perfected. It is used for chemical purposes.

MAGNESIUM

Electrolytic Reduction. Magnesium is another metal which is produced solely by electrolysis. In this case the double salt of magnesium and potassium chloride is kept molten in an iron receptacle and is subjected to the passage of the electric current. Chlorine is liberated at the anode, and the magnesium, alone, separates at the cathode.

Critical Details. The magnesium is not much lighter than the molten bath so care must be taken that the melt be kept as dense as practicable. Other salts, such as barium chloride, may be added for this purpose. The details of the process of manufacture are guarded closely, although the normal cost of production is considerably under 80 cents a pound. The novice finds much difficulty in getting rid of the chlorine, in preparing easily the pure anhydrous salt to be used, in collecting the magnesium together from the bath in which it diffuses, etc.

Uses. Unlike sodium, magnesium has uses for its own metallic properties. It is the lightest of the available metals and makes alloys which are strong and tough. With the increase of aviation there certainly will be greater demand for this metal.

Another use for reasonably cheap magnesium metal would be in deoxidizing other metals. Magnesium quickly combines with oxygen as found in molten steel or in other alloys, and would be used far more extensively if the price permitted. It is astonishing from the metallurgical point of view that, with magnesium compounds so abundant and with the metal presumably separated with no undue difficulty, the price could mount to $5 a pound and remain there for an entire year, as happened during 1915.

PLATINUM, PALLADIUM, IRIDIUM

Supply. These three metals are growing continually more valuable because their supply is not increasing while their use is, both for industrial and ornamental purposes.

The U. S. Geological Survey gives the world's production thus:

Country	1911 (oz.)	1912 (oz.)	1913 (oz.)	1914 (oz.)
Russia	300,000	300,000	250,000	241,200
Canada	30	30	50	30
New South Wales and Tasmania	470	778	1,500	1,248
Columbia	12,000	12,000	15,000	17,500
United States—crude	628	721	483	570
United States—all bullion	1,200	1,300	1,100	2,905
Borneo, Sumatra, etc.	......	200	200	......
	314,328	315,029	268,333	263,453

As the production of palladium and iridium probably is not over 1 per cent of the total number of ounces, it is plain how inadequate their

supply is. Practically this entire amount comes from placer deposits where the metal occurs as metallic grains containing 70 to 90 per cent of platinum and iron as the largest of a dozen other impurities.

Separation Process. *Standard Method.* The standard method of treating the metallic grains with aqua regia to dissolve the platinum gives a fair separation, but further treatment is necessary for the highest grade material. By this method the platinum in aqua regia is evaporated and the salt is taken up twice with hydrochloric acid to prepare for precipitating from clean chloride solution with ammonium chloride. The bright yellow ammonium-platinic chloride is dried, is heated to platinum sponge, and the sponge then is melted before the oxyhydrogen blowpipe.

Commercial Form. A commercial separation, carried out on doré silver from copper and lead refining, consists in treating with aqua regia the residue from the sulphuric acid parting for silver. From the metals remaining, platinum and palladium will be dissolved, and iridium will be left. The platinum will be precipitated as the double chloride; palladium will be thrown down by metallic zinc and melted into cakes. The iridium can be purified further by dissolving in silver and extracting again with acids. The main course of the procedure is simple, but the more the matter is studied, the less sharp the separations are found to be, and several treatments may be required to give strictly pure products.

Electrolysis. The wet treatment is not entirely satisfactory for recovering the gold from its bullion, so the electrolytic process already mentioned is in vogue largely now; this method, at the same time, separates palladium and platinum to go into the electrolyte and to be precipitated out, while osmium and iridium remain in the sludge and are recovered separately.

With high temperatures available, and with electrolytic separations to assist the wet treatment, the metallurgy of these metals is in a way to be used with much satisfaction, if the metals themselves only were available in quantity.

SEVEN ALLOYING ELEMENTS

Silicon, Manganese, Titanium, Vanadium, Chromium, Molybdenum, Cobalt

Adaptability for Ferro-Alloys. It is a significant fact that the above elements—to which may be added nickel and tungsten—make

excellent alloys with iron. They all are elements of high melting point; but whether they are oxidized easily at high temperatures, or not, makes little difference, if they are dissolved in iron. Their behavior is absolutely opposite to many low-melting elements which also alloy easily with iron and ruin it for all practical purposes—such elements are sulphur, phosphorus, arsenic, and aluminum.

Reduction. Cobalt is reduced easily from its oxide to metal, but most of the others require more energetic means. Silicon and manganese commonly are reduced with varying amounts of iron in the usual iron blast furnace, and their iron alloys are on the market in considerable variety and are used very much in steel making and in foundry work.

Fig. 49. Typical Thermit Crucible
Courtesy of the Goldschmidt Thermit Company, New York City

All of these elements can be reduced with iron in electric-arc furnaces; some, indeed, can be reduced quite pure, except for carbon, which it is difficult to prevent combining under such circumstances.

Aluminothermic Method. But a method is available which is used considerably now since aluminum has become reasonably cheap; this is to reduce the purified oxide of the metal in question with metallic aluminum. This is called *aluminothermics.* A crucible like that seen in Fig. 49 commonly is used. The oxide, or the mixture of oxides, if an alloy is to be made, is mixed with fine granular aluminum and is placed in the lined steel cavity of the crucible. If the mixture is brought to reacting temperature at any one point, the activity spreads quickly throughout the mass, and in a few seconds the newly formed metal can be tapped out into suitable molds. A bit of ignition powder is used to start the reaction. The temperatures produced are extremely high, for the heat has no chance to dissipate in the few seconds of the reaction, and alumina has by far the highest heat of formation of any of the common oxides whose metals are used. The alumina formed by the reaction

floats (it fuses at 2000° C.) on the metal reduced and can be recovered as a by-product.

New alloys continually are being developed by this process. Besides quite pure cobalt, chromium, and manganese, as well as their iron alloys, there are on the market ferrotitanium, ferrovanadium, and ferromolybdenum, and numerous other alloys produced by aluminothermics.

WELDING LIGHT SHEET-METAL TANKS AND CONTAINERS BY THE OXWELD PROCESS

WELDING

INTRODUCTION

Welding an Ancient Art. The art of joining metals is one of the oldest known to man. Ever since the first cave dweller or half-monkey man hammered his first piece of iron or copper between two stones, the development of the art has gone forward, and will probably continue to develop as long as men use metals. The welding of iron is apparently as old as the production of that metal by man, for there is, in a temple yard of the ancient city of Delhi, India, an iron pillar nearly two thousand years old, which shows unmistakable evidences of having been welded. The shaft projects 22 feet above the surface of the ground, extends over 40 feet into the earth, and is about 16 inches in diameter. It was apparently welded into one piece from blooms of about 70 pounds weight each; the joints are as perfect as could be made with our most modern equipment, and yet they were forged by hand.

Conditions for Successful Welding. Strictly speaking, "welding" is the uniting or joining of two pieces of metal by hammering them together while they are hot enough to be plastic and the application of the term would thereby be limited almost entirely to work done in a blacksmith shop. But modern methods of obtaining high temperatures by gases and electricity have made possible the development of other and better methods of joining metals, many of which cannot be welded by hammering. Custom has applied the term "welding" to these also, although some of them are really brazed or soldered with metals of high melting temperatures. Any process by which cohesion between the molecules of the pieces to be joined is brought about may be called "welding".

Metals are most easily welded when in that degree of plasticity between the molten and the solid states; hence, those metals which remain plastic the longest while cooling are the easiest to weld. Originally welding was limited to such metals as iron, platinum, nickel, and gold but the recent development of high temperature

systems has extended the field greatly. In fact, it is safe to say that every metal may be welded by some one or other of the modern methods. So recently as five years ago it was considered impossible to weld aluminum; but this is being done successfully today with the electric-arc system, using the graphite electrode, and practically every kind of alloy is also being welded by both the electric-arc and the gas systems.

Successful welding by any method depends almost entirely upon three factors: flow, cohesion, and temperature. The metal must tend to flow under great pressure, even if but to a slight degree. The surfaces of the pieces to be welded must tend to "wet" each other or cohere to an appreciable extent. The working temperature must be that at which the foregoing conditions are most prominent. The best welding condition for iron and steel exists within a limited range of temperature only and, when in this condition and at this temperature, they possess the property of expanding when cooled and contracting when heated. Therefore, modern welding systems are designed to take advantage of these well-known laws in the best and most economical manner, or else they are not considered commercially desirable and will, therefore, soon be abandoned.

It is for the purpose of describing in a general way these systems and their applications that this book has been compiled and it is our desire that all students of the art of welding may profit to the highest degree through their study of this subject. The field is expanding rapidly and great financial gains should be possible to the well informed during the next few years.

METALS AND THEIR NATURES

Iron and steel are the most useful and the most used metals we have and, since steel is merely iron with the addition of a small percentage of carbon and a few other elements, we will consider iron first.

Iron. Iron is made by taking iron ore, placing it in a furnace with fuel (coal, coke, or charcoal) and a suitable flux (usually limestone), and then melting it with the assistance of a forced draft until the ferrite in the ore is reduced to metallic iron. This is then run out into molds to form the "pig iron" of commerce. If this pig iron is again melted in a cupola and cast into molds of various shapes, it

is called "cast iron" and is the material so largely used now for machinery and other articles.

Cast Iron. Cast iron is hard and brittle and granular in composition, because it contains so much carbon. This latter substance has come from the fuel used in melting the iron and the carbon content can be varied to suit requirements by "burning" it out. This is done by forcing a strong blast of heated air through the iron while it is still molten, causing the oxygen in the air to combine with the carbon and carry it off in the form of carbonic-acid gas, (CO_2). Charcoal makes the best fuel for use in smelting because it is so free from sulphur and other impurities and it is used when making so-called Swedish iron. Good charcoal iron is easily welded and will stand more bending without breaking than any other kind of iron. Wrought iron is almost entirely free from carbon and is very malleable and ductile, hence easily welded.

Steel. Steel is wrought iron with an appreciable percentage of carbon added, the amount depending upon the use to which it is to be put. It is made by simply stopping the air blast when making iron and leaving a small amount of carbon in the metal. This is usually at the point where the mixture still possesses the ductility and malleability of wrought iron together with the hardness and brittleness due to the carbon. This is why steel is both tough and hard and the amount of carbon determines the hardness. While wrought iron is slightly fibrous, steel is crystalline, but it may be improved by working at the proper temperature, and good steel is homogeneous throughout.

Soft Steel. Soft steel, or "mild" steel, as it is called commercially, contains very little carbon and is really on the dividing line between iron and steel. When it is made by forcing air through the molten iron to burn out the carbon, as previously described, it is called "Bessemer" steel, after the inventor of the process. The desired amount of carbon is afterwards supplied by adding an iron called "spiegeleisen" which contains both carbon and manganese, the latter enabling the iron to hold a larger amount of carbon and adding to its strength.

Open-Hearth Steel. Open-hearth steel is made by melting cast iron in an "open hearth" or broad shallow furnace and adding the proper proportions of scrap wrought iron or steel and iron ore. This

is a very tough steel and is used for boiler plates and similar articles.

Per Cent of Carbon in Steel. In all of the processes the steel is cast into ingots and then rolled or forged into bars, sheets, or other shapes for commercial purposes. The amounts of carbon in iron and steel are approximately as follows

Cast Iron	3. % to 4.5%
Tool Steel	.5% to 2 %
Mild Steel	.1% to .5%
Wrought Iron	Less than .1%

Steel Castings. Steel castings are usually made of mild steel and contain small amounts of manganese, silicon, sulphur, and phosphorus in addition to the carbon. Manganese and silicon improve the steel but sulphur and phosphorus are not desirable. Aluminum is also added sometimes as a solidifier or deoxidizer before pouring the castings and it improves their quality. The amounts of these elements in steel castings usually vary as follows

Carbon	.18% to .75%
Manganese	.30% to .80%
Silicon	.27% to .33%
Sulphur	.032% to .056%
Phosphorus	.032% to .092%
Aluminum	Traces only after melting

Steel Alloys. The various elements used to alloy iron are technically known as "impurities", even though their addition is a distinct advantage. All of the alloys of iron and steel may be welded by any of the modern methods, although some of them cannot be welded by the blacksmith. *Silicon* causes brittleness and too much of it prevents welding, on account of the crystalline structure of the alloy, but the addition of manganese tends to overcome this and make it more weldable.

Manganese up to 1.5 per cent may be added to iron or steel without preventing welding, but more than that makes a brittle alloy. Manganese reduces both the sulphur and oxygen in the iron and adds greatly to its strength. *Nickel steel* may be welded and the addition of nickel up to 5 per cent is safe, if the amount of carbon is kept small. Nickel increases the tensile strength of steel without impairing the elasticity and also tends to prevent rusting of the iron alloy. *Chrome steel* may also be welded successfully.

Copper. Copper is one of the elemental metals and is found as an ore and in a pure state. The ore must be smelted and the copper refined before it is ready for use in the arts like other metals. It is cast and sold in the form of ingots and should be at least 99.5 per cent pure and entirely free from sulphur. It is used largely in the form of sheets, bars, and tubes and occasionally it is cast in molds like iron and steel.

It is the principal element in brass, bronze, gun metal, and many other alloys, and is nearly as useful to man as iron. It can be welded readily by any method, although this is rarely done, for brazing and soldering have been the processes generally used for joining or repairing pieces of it. Great care must be exercised when casting copper to insure its being properly deoxidized and the same thing applies to welding it. Silicon, aluminum, and phosphorus are used for this purpose, although aluminum alone presents the disadvantage of oxidizing rapidly when exposed to the air.

Bronze. Tin and copper form a good alloy called "bronze", which is harder than either metal alone. The addition of tin increases the fluidity of copper but diminishes its ductility; the strength of copper is increased by adding up to 12 per cent of tin, and its crushing strength is increased by additions up to 18 per cent of tin. Beyond this latter point the bronze becomes hard and brittle. "Gun metal" is copper with from 8 per cent to 2 per cent of tin but the best alloy contains about 10 per cent of tin. Great care must be used when welding alloys containing tin because the latter melts at a comparatively low temperature and may easily be burned when welding.

Brass. Zinc and copper form the alloy known as "brass", and percentages of zinc as high as 40 per cent are sometimes used without serious effect on the malleability or ductility of the alloy but more zinc makes it very brittle. Tin is sometimes added to brass to increase its strength. Zinc is a good deoxidizing agent for copper but it vaporizes quite rapidly at high temperatures. This causes the zinc to pass out of the alloy, leaving the copper porous or spongy; this is why brass is so hard to weld satisfactorily. Lead is also used as an alloy for copper but not over 3 per cent can be used because it does not mix well.

Manganese Bronze. Manganese is alloyed with copper in various proportions for certain purposes. This alloy is known as

"manganese bronze" and may be both forged and welded by proper methods, although welding is a rather hard process to perform satisfactorily with it. The ductility and strength are both very high and the alloy does not corrode easily, even in salt water. It weakens slightly when heated and shrinks more than gun metal; hence it requires special care during welding operations.

Phosphor Bronze. Phosphorus is also used with copper for making bearing metals and makes a strong alloy which resists corrosion. The percentage of phosphorus used when making "phosphor-bronze" castings ranges from 2 per cent down to but a few hundredths of one per cent; frequently the phosphorus causes hard spots because it does not always combine freely and thoroughly. This alloy is also hard to weld readily, although it may be done by proper methods.

Aluminum. Aluminum is the lightest of the commercial metals and is very valuable for forming alloys but it is rather hard to weld or solder because of the rapidity with which it oxidizes, especially at high temperatures. Castings of aluminum are being successfully welded now, however, by several methods; and sheets of aluminum are welded by the gas methods. The various alloys are also being welded; the heat conductivity is comparatively high and it acts like solder when melted; it melts at 655 degrees centigrade; it is easily burned; and a sort of scum forms on the surface, if welded with a high-oxygen flame.

Commercial welding is confined almost entirely to the metals here described, although gold, silver, platinum, and a few others are weldable and are used in some of the finer arts. The characteristics of iron, steel, and copper, however, are most important to remember in connection with commercial welding and manufacturing.

WELDING PROCESSES

Classification. While it is true that there are many variations of the principal processes of welding and joining metals, they may safely be placed in one of four general classes: smith or forge welding, electric welding, gas or hot-flame welding, and chemical welding. Included with these are such allied operations as soldering, brazing, and riveting for joining metals; so some reference will also be made to them, although the latter cannot be considered as welding in any

sense of the term. Riveting is treated of here because it is one of the processes being superseded by the modern welding systems for some classes of manufacture, and the student should have some knowledge of the process and its relative value.

Smith Welding. Smith welding, or forging, is the general process of forming or joining metals by hammering or pressing the pieces into the desired shape and may be done either hot or cold, depending upon circumstances. When joining two or more pieces of metal, especially iron or steel, it is done hot and is one of the oldest of the useful arts. It is the most common of all of the welding processes but depends more upon the skill of the operator than any other process of welding; hence it is gradually being superseded by them. It is also rather expensive and slow and is not so suitable for large or heavy work as some of the other systems.

Electric Welding. Electric welding has been used as a laboratory process for a number of years but has recently been developed commercially to such an extent that it is rapidly coming to the front as the most important of all of the welding processes. Five different systems have been developed for using electrically generated heat for welding purposes, each of which has been named in honor of the inventor. These are the Thomson, Zerener, Benardos, Slavianoff, and LaGrange-Hoho systems, of which the Thomson has two forms, viz., "butt welding" and "spot welding," the names indicating the kinds of joint formed.

The *Thomson system* requires the use of alternating current whereas the other systems use direct current for welding. The Thomson system and its latter day modifications consist in bringing together the two pieces to be welded, in a special machine, passing an alternating current through the point of contact until the parts are heated sufficiently to be soft and then squeezing them together until they unite. The heating is due to the resistance of the joint to the passing of the current before the parts are soft enough to weld.

The *LaGrange-Hoho system* is also based on resistance and consists in placing the pieces of metal in a bath of electrolyte, causing the current to flow to them from a positive electrode and heating them until soft enough to weld. The actual weld is made by hammering, the same as smith welding; so this is not at present a very important process commercially.

The three other processes use the electric arc as the source of heat, and do their work by filling in additional material to join the pieces. The *Zerener system* is based upon using two pieces of carbon in a suitable holder, causing the arc or flame to be deflected toward the work by means of a magnetic field and using the arc to melt the filling material. The *Benardos system* consists in using a piece of carbon or graphite as one electrode for the arc, drawing the arc between the carbon and the work (which is the other electrode) and using the heat of the arc to melt the filling material required for joining the pieces.

The *Slavianoff system* also consists in drawing an arc between the work and an electrode, but a piece of the filling material is used as one of the electrodes and melts directly into place on the job. This is the most important of the electric welding processes, although it is the most recently developed to a commercially practical point. It is applicable to practically every class of welding and for nearly all metals, and is the simplest of all welding processes. It will probably be in universal use within a very few years.

Gas Welding. Gas welding, or hot-flame welding, is at present next in importance to smith welding and is applicable to many kinds of work which cannot be done by forging. The three most important processes commercially are known as the *Oxy-acetylene, Oxy-hydrogen,* and *Blau-gas processes.* All of these processes consist in using oxygen and another gas to give a flame of sufficiently high temperature and heating capacity to melt the material to be welded, the gas used with the oxygen being indicated by the name of the process. In all cases the oxygen and other gas are mixed in a suitable burner and the flame directed on the work in such a way as to cause the metals to flow together and, when no extra material is added to form the weld, it is said to be "autogenous" or self-forming. Electric-arc welding is also autogenous to the same extent, although the term is not strictly correct. The details of these systems will be described later.

Chemical Welding. Chemical welding is exemplified today almost exclusively by the process known as "thermit welding" and consists in igniting a mixture of oxide of iron and aluminum so as to set up a chemical reaction which evolves an intense heat. This is done by placing the mixture in a suitable mold and igniting, causing the aluminum to reduce the iron from its oxide, thus evolving

the heat required and forming what is called "thermit-steel". The molten steel is allowed to run out of the mold and into and around the part to be welded, thus forming a "cast-weld" of considerable strength. A suitable mold must also be formed about the part worked upon in order to retain the metal until cooled; so this process is comparatively slow and expensive. Several other chemical processes have been developed but as they are not of very great importance commercially at this time, they will not be described here.

Brazing and Soldering. Brazing and soldering are processes which approach welding so closely in some of their applications that they are worthy of serious consideration as a part of that subject. *Brazing* consists in joining metal by fusing a filling material called "spelter" into the joint by heating, first preparing the surfaces of the joint with a suitable flux. When brass is brazed, it really becomes a welding process because brass is the principal constituent of spelter. The heat is produced by a gas flame and the work is done at a comparatively high temperature.

Soldering, or "metallic gluing", as it has been called, is done by melting a soft alloy into the space between the parts to be joined. It can be done with a gas flame or a heated soldering copper and at comparatively low temperatures. Soldering is a comparatively old process, is cheap, easily learned, and in wide use, but it should not be used for any joint requiring much strength. It is not suitable for joints in iron or steel or in several of the alloys.

Riveting. Riveting consists in joining plates, sheets, or other shapes of metals by means of small pieces of metal which pass through the parts and are headed over on both sides. This process is also old and will be described in detail later in order to bring out the comparison between this and the newer methods of joining materials.

Miscellaneous Processes. Several other processes of joining metals are being advocated by their inventors, among which may be mentioned the "Ferrofix brazing process" and the "Laffitte welding plate", although neither of them is in very extended use at present. *Ferrofix brazing* consists in cementing together two pieces of iron by means of a thin film of brass in such a way that the brass alloys with the iron and forms a joint that is stronger than the iron.

The necessary heat is supplied by a gas flame of suitable temperature. *Laffitte welding plate* consists of a special chemical preparation molded over a sheet of wire gauze and it is used by placing the plate between the surfaces to be welded. The parts are heated to a cherry red, the plate inserted, and the pressure applied while the reaction takes place. The preparation of the plate is such that it supplies the flux, the reagent, and the filling material and makes a joint of relatively high strength. Both of these processes have been introduced into the United States but recently and their relative values have still to be determined; they will be described in detail later.

SMITH WELDING OR FORGING

Smith welding is the process of joining metals by laying the pieces together and hammering at the place of contact until they become one piece. Most metals must be heated nearly to the temperature at which they begin to flow, before they can be welded. For iron and steel this is at the white heat; so let us first consider the action of the fire and the equipment required before taking up the study of the process in detail.

Producing the Proper Temperature. The combustion of fuel, either coal, coke, oil, or charcoal, causes the oxygen of the air to combine with the carbon of the fuel, and this chemical combination is what produces the heat. The *amount* of heat produced depends upon the amount of carbon and oxygen combined during combustion; whereas, the *temperature* attained depends entirely upon the rapidity with which the combination takes place. This is one of the most important facts to be learned in connection with welding, because the principle involved applies to all of the other systems of welding as well as to smith welding.

Forced Draft. Ordinarily, combustion would not be rapid enough to generate the amount of heat required for welding; so a draft is created through the fire in order to supply enough oxygen to the fuel and increase the rate of combustion. Too much air will chill the fire or blow it out, and an excess of oxygen will cause some of it to combine with the iron and form a scale of oxide of iron. This is called an "oxidizing fire"; whereas, if the oxygen is all consumed in the fire and there is an excess of carbon, it is then called a "reducing fire".

Fuels. Coal, coke, charcoal, oil, and gas are all used as fuels for forges, but charcoal is the best because it is almost free from impurities. Coal and coke are good unless they contain sulphur and phosphorus. Sulphur makes iron "hot-short", or brittle when hot, and phosphorus makes it "cold-short", or brittle when cold.

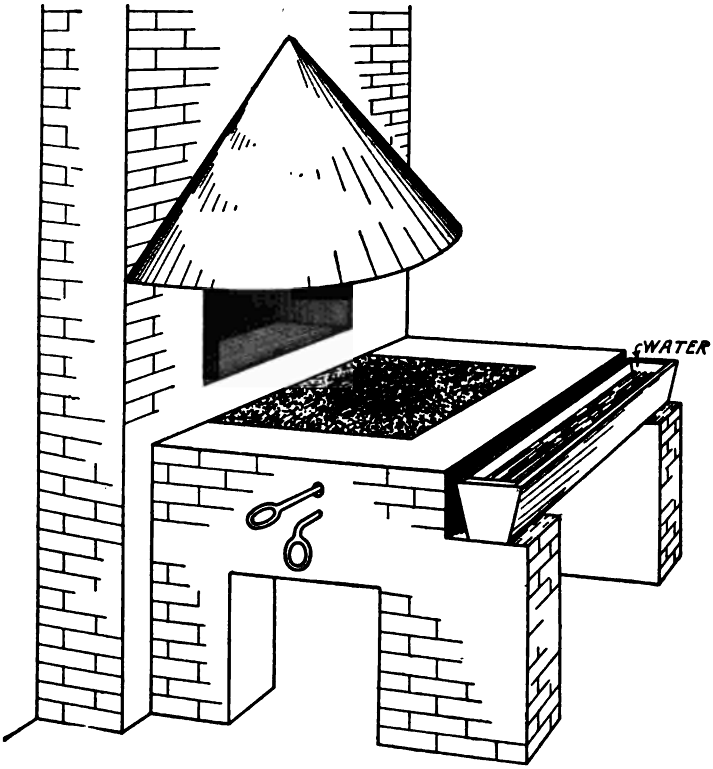


Fig. 1. Brick Blacksmithing Forge

Copper, lead, tin, and other non-ferrous metals should be kept out of the forge as they will spoil iron for welding.

Forges. Forges are of various kinds, usually of brick or iron, Figs. 1 and 2, and consist primarily of a bowl with an air inlet or "tuyere" in the center of the bottom, a hood overhead to carry smoke and fumes to the chimney, a blower or bellows to supply air, an ash pit, and a trough or other vessel for water. Usually a blast of air at a pressure of from 4 to 6 ounces per square inch should be maintained. A type of portable forge is shown in Fig. 3.

Forging Tools. *Anvil.* An anvil is required to provide a surface upon which to lay the pieces, when hammering to make the weld. It may be of cast steel or of wrought iron with a steel face, and usually weighs from 150 to 200 pounds. The anvil should be placed on a block of hard wood, Fig. 4, and securely fastened to it, and the height should be such that a man's knuckles will just reach to the top of it when he stands alongside.

Hammers. Hammers and sledges of various sizes and styles are required. Hand hammers, Figs. 5, 6, 7, and 8 weigh from 1 to

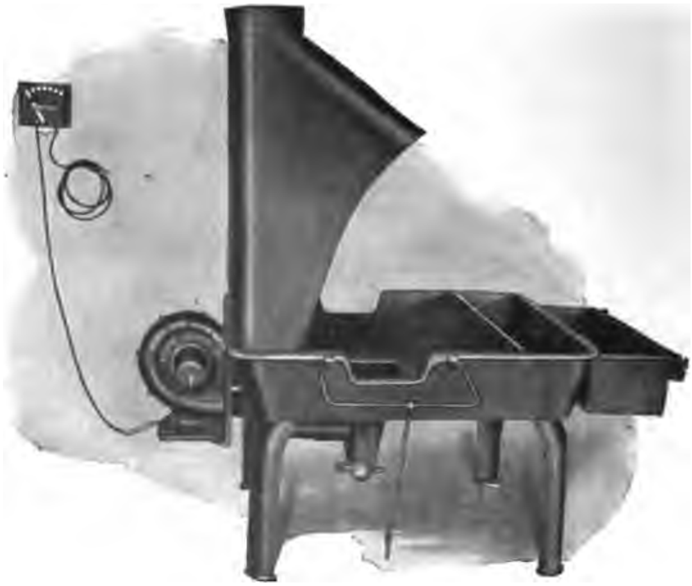


Fig. 2. Modern Motor-Driven Forge
Courtesy of Canedy-Otto Company

2½ pounds and have handles from 14 to 16 inches long. Hand sledges, Fig. 9, weigh from 5 to 8 pounds and have handles from 24 to 30 inches in length. They are handled by a helper. Swing sledges, Fig. 10, weigh from 8 to 20 pounds and have 36-inch handles. They are used for heavy work only and the helper strikes a blow with a free full-arm swing.

Ball-peen, or chipping, hammers, Fig. 7, have a round top or ball-shaped peen on the head. The striking face is flat, but the peen head is used for riveting or for stretching metal by hammering. Cross-peen hammers, Fig. 8, have a long ridge running across the

Fig. 3. Portable Hand Forge
Courtesy of Canedy-Otto Company

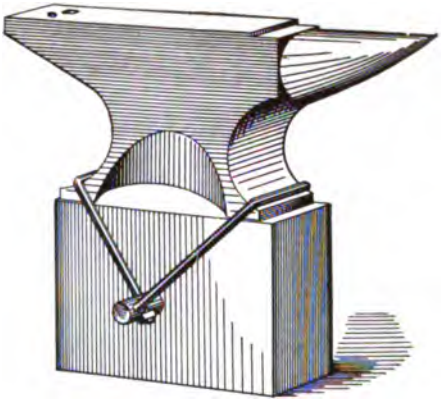


Fig. 4. Anvil Fastened to Block

top of the head and are used when stretching metal lengthwise and for riveting. Straight-peen hammers, Fig. 5, have a ridge running lengthwise of the head and are used when the metal is to be spread sidewise. Hammers should be selected to suit the work to be done and the strength of the user, and they should be of the best quality.

In addition to the foregoing hammers for general use, there are

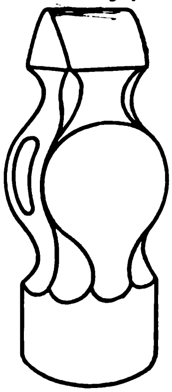


Fig. 5. Straight-Peen Hammer

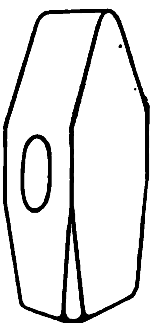


Fig. 6. Long-Peen Hammer

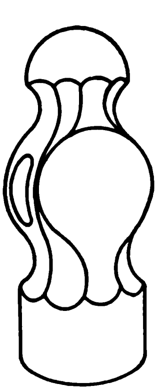


Fig. 7. Ball-Peen Hammer

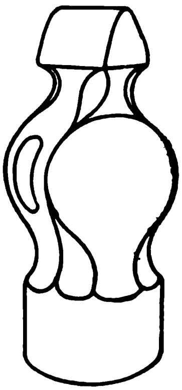


Fig. 8. Cross-Peen Hammer

various kinds for special purposes. These include "set" hammers of various shapes, for forming the iron. Square set hammers, Fig. 11, are for producing flat surfaces; flatters, Fig. 12, are for similar use but cover a wider area; fullers, Fig. 13, are for spreading out the iron, hollowing out work, and forming shoulders; swages, Fig. 14, are for rounding pieces of iron and are of numerous sizes; punches, Figs. 15 and 16, are for making holes and are made square and round; and cutters, Figs. 17 and 18, are hammers with chisel-like edges on the top of the head for cutting bars, etc.

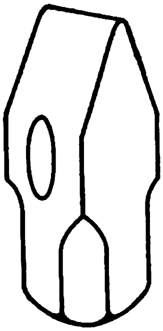


Fig. 9. Hand Sledge

Anvil Tools. Anvil tools with stems to fit the square "hardie" hole in the anvil are made in shapes to match the set hammers previously described. They include fullers, swages, hardies, heading tools, etc., Figs. 19 and 20.

Tongs. Tongs are of many kinds and special ones are easily made when peculiar pieces are to be worked. Flat tongs, Fig. 21, are used for flat iron bars, strips, or plates. Pick-up tongs, Fig. 22, have curved springy jaws and are used for handling small pieces. Bolt tongs, Fig. 23, have a sort of pocket in the head or jaws for holding bolts while forming them. Gad tongs, Fig. 24, are shaped somewhat like bolt tongs except that the nose of the jaws is flattened somewhat like flat tongs. They are used for holding

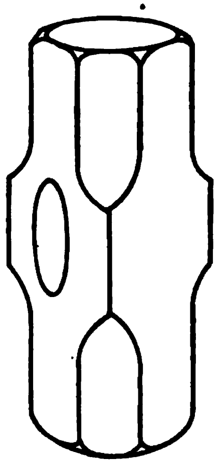


Fig. 10. Swing Sledge

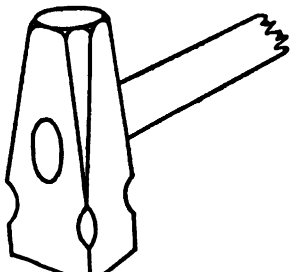


Fig. 11. Square Set Hammer

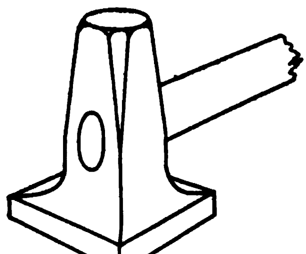
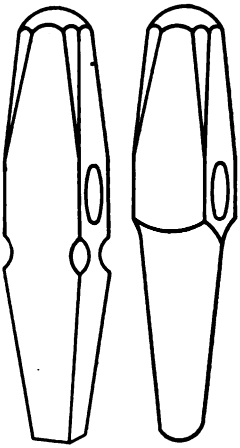


Fig. 12. Flatter

Fig. 13. Fuller Fig. 14. Swage
Courtesy of Vaughan and Bushnell Manufacturing Company

flat pieces which are thick at one end or side. Tongs soon become spoiled by the constant dipping in water and they bend out of shape easily while hot. They should not be left in the fire unless necessary and should be kept in a rack when not in use.

Miscellaneous Equipment. In addition to the foregoing essential equipment, smith shops frequently contain many other tools such as dies, swage blocks, vises, surface plates, gages, taps, dies, calipers, Figs. 25 and 26, etc. For handling the fire there should be provided a poker, fire hook, shovel, sprinkler, and ladle, Figs. 27 and 28. A monkey wrench, chisel, and a pair of "C" clamps are also useful, and a tapered mandrel will be needed if rings are to be welded. A large portion of the equipment here mentioned will also be required for welding by any other method and a well-equipped shop is generally a good investment. On the other hand, it is usually better to start with the smallest equipment which will do the general run of the work and then buy special tools and equipment which experience shows to be necessary.



Figs. 15 and 16. Square and Round Punches

Figs. 17 and 18. Cold and Hot Cutters
Courtesy of Vaughan and Bushnell Manufacturing Company.

General Features of Smith Welding. The process of smith welding, or forging, is comparatively easy to learn, but skill and

the ability to use the process successfully will only come after long practice. The first operation to learn is to heat the iron properly; this is done by placing it in the fire until it reaches a bright red, almost white, color. Large pieces will take longer to heat, and will remain

Fig. 19. Bottom Fuller and Swage and Hot Hardie
Courtesy of Vaughan and Bushnell Manufacturing Company

Fig. 20. Heading Tool

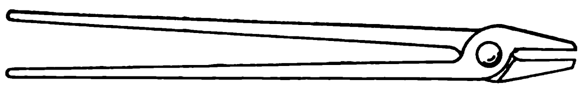


Fig. 21. Flat Tongs

Fig. 22. Pick-Up Tongs

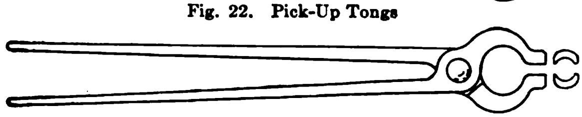


Fig. 23. Bolt Tongs

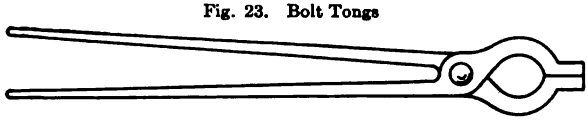


Fig. 24. Gad Tongs

hot longer, than small ones and the surface will tend to oxidize and flake off upon exposure to the air while hot. For ordinary forging operations this is no disadvantage beyond reducing the size of the piece slightly but, when welding two pieces together, this oxide

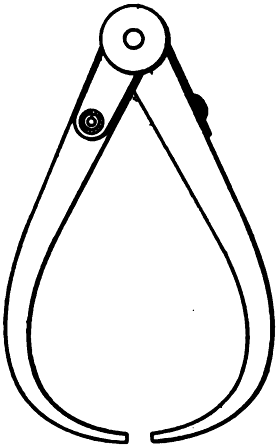


Fig. 25. Outside Calipers

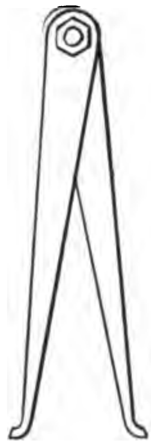


Fig. 26. Inside Calipers

must be kept off by the use of a good flux or it will destroy the value of the weld by preventing cohesion of the particles forming the pieces. The most common flux for iron is clean sharp sand because it will fuse and stick to the surface and keep out the air; but work can be done without a flux, if it is done quickly. For steel, it is better to use potter's clay, wet with strong brine and then dried and powdered. Borax is sometimes used but it is not good for the metal.

Simpler Operations Performed First. The simpler operations of forging should be learned first and then the welding tried after-

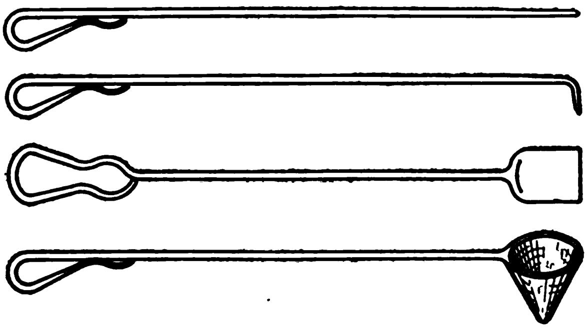


Fig. 27. Types of Fire Handling Tools

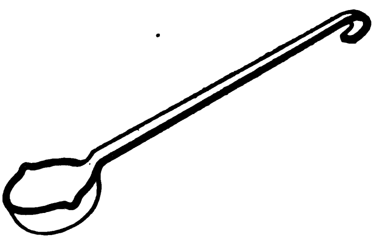


Fig. 28. Ladle

wards. "Drawing" is the operation of stretching the iron in one or two directions and it consists in hammering the hot piece on all sides for lengthening or on one side for flattening or spreading. If the piece tends to curl, it can be hammered on both sides to keep it

flat. Square pieces should be turned over and over and hammered on all sides in drawing, and round ones should be hammered on all sides. "Upsetting" is the operation of increasing the diameter or thickness of a piece by heating and then hammering it on the ends until it becomes shorter through the flowing of the metal to the heated portion. The bar usually tends to bend under this operation; so it should be straightened at once by hammering on the high side. Considerable heat is required for upsetting and the fibers tend to separate or split apart, when the piece is hammered lengthwise of its grain; so it is well to finish the upsetting by heating again and hammering all around to weld the fibers again. Bolt heads are formed by upsetting the bar on the end and hammering square, or hexagonal, as required.

When forming corners which must be square, the pieces must first be upset to get enough stock and, when making connecting rod straps, crank shafts, rocker arms, hook eyes, eyebolts, axe heads, armature shafts, and other articles of variable thicknesses, it is customary to upset them from straight bars before beginning to shape them. After the student has practiced the more elementary operations described and becomes familiar with his tools and his metal, he can then try welding.

Kinds of Welds. There are several kinds of joints made by smith welding, each of them being known by a name which indicates the manner in which the pieces are joined. These are the "scarf weld", "butt weld", "lap weld", and "cleft weld", and the proper one to use will depend upon the shape of the piece and the strains it will meet in service.

Scarf Weld. The scarf weld, Fig. 29, is made by "scarfing", or thinning the pieces at the end, in order to give them a bevel; the iron should be upset a little to give enough extra stock to allow for the drawing down when hammering. The pieces should be rounded slightly on the surfaces which come together in order to allow the scale and slag to squeeze out and then they should be hammered while at a white heat. When they are thoroughly joined, the piece should be shaped all around by turning while hammering.

Butt Weld. A butt weld consists in hammering two pieces end to end until they unite, the pieces being rounded slightly on the ends, Fig. 30, to allow the scale to come out. This operation will tend to

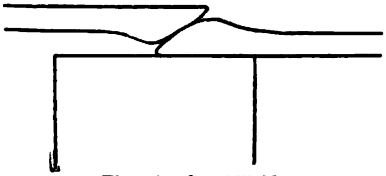


Fig. 29. Scarf Weld

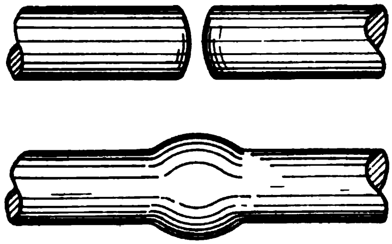


Fig. 30. Butt Weld

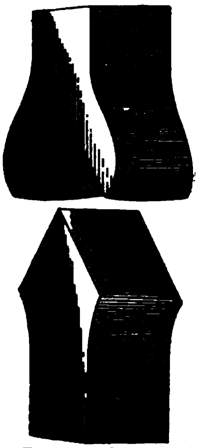


Fig. 32. Cleft Weld

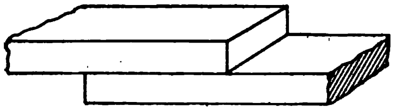


Fig. 31. Lap Weld

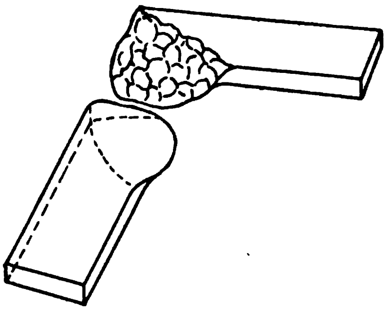


Fig. 33. Corner Weld

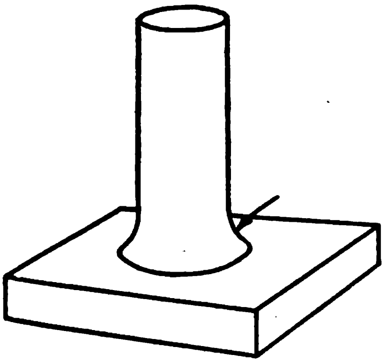


Fig. 34. Jump Weld

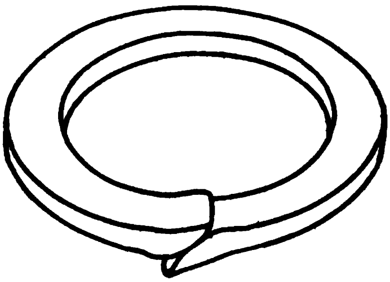


Fig. 35. Ring Weld

upset the pieces and they should be drawn down to size again after welding. This sort of a joint is not so strong as a good scarfed joint.

Lap Weld. A lap weld, Fig. 31, is made by simply laying one piece on top of the other and hammering until they unite. Work should start at the center and proceed toward the outside in order to force out the slag; otherwise the metal will not unite. It is not necessary to round up the parts for this joint, but a better job is insured if it is done.

Cleft Weld. A cleft weld, Fig. 32, makes the strongest joint and consists in splitting one piece at the end, tapering the other piece, and slipping it into the fork of the first piece; then, by hammering the sides of the cleft together, the pieces are made to unite. The pieces should be first hammered on the ends in order to drive them tight together in the cleft, and it is good to round the sides of both pieces on the welding surfaces to allow slag to flow out.

Applications of Smith Welding. The applications of smith welding are numerous, but a few of them will serve to give an idea of the possibilities. Scarf welds are used to form the corners of frame work made of flat bars, Fig. 33, and one piece is beveled on the end and the other on the side and the joint is made as previously described. Jump welds, Fig. 34, are also made by scarfing the pieces in the same way and welding; and rings, Fig. 35, are made by scarfing the ends of the strip and welding. To determine the length of a piece for making a ring, add the thickness of the stock to the inside diameter of the ring and multiply by $3\frac{1}{7}$. For straight pieces to be welded, add the thickness, or diameter, to the length to allow for the joint.

Butt welds are used, when joining heavy pieces—especially pieces of irregular shape that are to be upset first—and for lengthening pieces of large cross section, such as shafting. Lap welds are used for comparatively thin sections like steel tires, hoops, and plates, and sometimes for making tanks and large piping. Tubes are sometimes lengthened by swaging one part large enough to slip over the other and then lap-welding them by hammering with a mandrel inside to prevent distortion, and to give something to act as the anvil to hammer against. Cleft welds are used when welding steel to iron, as, for instance, putting hard tips on picks, attaching tool

steel drills to soft shanks, etc., and for work requiring great strength of joint, such as tie-rods for bridges. Borax should not be used as a flux for this purpose, unless it has first been calcined or melted in a ladle, cooled, and powdered in order to remove all moisture from it. When making a weld between iron and steel, it is best to heat them both at once; dip the iron in sand and the steel in borax; reheat the iron white and the steel cherry red; and then weld with a heavy hammer. After they are joined, they should be reheated and then finish with a lighter hammer. Steel facing is another welding operation and consists in welding a piece of steel flatwise against the iron to give it a hard surface; it is used in making some kinds of tools.

SOLDERING AND BRAZING

Both the soldering and brazing processes are similar to welding in so far as they are methods of uniting metals, but they are different in that the filling or joining material is usually of different composition from the pieces joined. The work of brazing brass and soldering lead resembles the welding process without the hammering but it is not welding in the proper sense of the term; it is, rather, a sort of "metallic gluing" process.

Soldering

Soldering is the process of joining pieces of metal by filling the space between them with material known as "solder", and doing it in such a way that the solder will adhere to both of them and hold them together. The first requirement of a good solder is that it will "wet" the surfaces, or amalgamate with the pieces to be joined. Alloys of lead and tin, with the addition at times of other metals, are the usual solders, although special solders are made without either of them. Soldered joints are not so strong as welded or brazed joints because of the material used but they are frequently used because they are easily and cheaply made.

The process requires less heat than welding or brazing and the joints may be cooled rapidly. An ordinary gas flame with a foot pump for the blast, or even a candle and a blowpipe, may be used for soldering. If the piece worked upon is so large that it rapidly conducts away the heat, a gasoline or kerosene torch is used to pre-

heat the piece and prevent chilling the solder. The blowpipe is used for small work like jewelry and the only point to watch is to be sure the flame is hot enough to burn all of its carbon. The blue center of a flame is highly oxidizing whereas the yellow outside portion causes a reducing action.

Fluxes. Fluxes are essential to successful soldering and there are several kinds on the market, although most operators soon learn to make their own. The fluxing materials generally used are salammoniac zinc-chloride solution, rosin in alcohol, borax, and tallow. Flux is used to dissolve grease and to remove any oxide present after cleaning. It combines chemically with the oxide and leaves a clean surface of metal which the solder will wet. Sometimes the flux is combined with the solder when making up the sticks, and this is known as "self-fluxing" solder.

Fig. 36. Soldering Copper
Courtesy of Central Electric Company

Tools. The tools required for soldering are very simple and few in number. The source of heat for the operation is usually a soldering "copper" or "bit," Fig. 36, which has in turn been heated in a gas or charcoal stove, Figs. 37, 38, and 39. It is made with a comparatively large head, small shaft, and wooden handle and has a pointed tip on the head for working. The tip should be "tinned" before using, and this is done by first cleaning and sandpapering, fluxing with zinc chloride, and heating. While hot it is rubbed well with a stick of tin which adheres to the surface, and it will remain tinned for a long time unless heated to a red heat. A type of grooved soldering copper is shown in Fig. 40, and an electric soldering tool is shown in Fig. 41.

Fig. 37. Soldering Iron Heating Stove
Courtesy of Central Electric Company

Solders. Most solders melt at about 200 degrees centigrade (392° F.), the softer solders melting at about 180 degrees centigrade (356° F.) and harder solders at about 330 degrees centigrade (626° F.).

There are so many special solders on the market that no closer figures can be given, but these will be a safe guide for most of the ordinary

Fig. 38. Charcoal Stove
Courtesy of M. Klein and Son

Fig. 39. Gasoline Furnace
Courtesy of Central Electric Company

kinds of work. Ordinary solder is half tin and half lead. Hard solder is two parts lead and one part tin. Antimony is sometimes

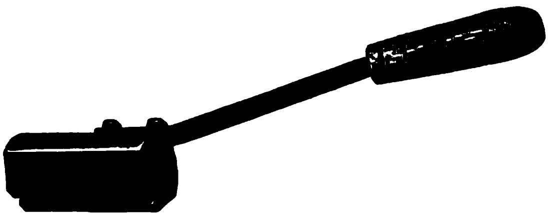


Fig. 40. Grooved Soldering Copper
Courtesy of Central Electric Company

added to harden and stiffen solder, and arsenic is added to make it flow more freely. Bismuth makes the solder brittle and cadmium

Fig. 41. Electric Soldering Tool
Courtesy of Central Electric Company

makes it soft. When bismuth and cadmium are both added they reduce the melting point, and "Wood's metal", which contains two

parts of tin, two of lead, two of cadmium, and eight of bismuth, melts at 70 degrees centigrade (158° F.). Copper strengthens solder but raises the melting point very rapidly.

Soldering Process. The process of soldering consists in first scraping the surfaces clean; heating the pieces to the soldering temperature by any suitable means; fluxing the surfaces to be joined; applying the solder with the solder bit; and finishing the joint by smoothing off. Rust and grease must be scraped or washed off with some alkaline solution. With liquid fluxes it is best to apply them after heating the surfaces to be joined, in order to eat away the film of oxide and keep the surface clean but, with borax or rosin solutions, it is best to apply them cold. After the surfaces are properly cleaned, heated, and fluxed, the solder is melted on with a flame or by rubbing with a hot bit and then the joint is smoothed up.

The most important points to watch are the temperature and the flux. Too much heat causes oxidation, makes the solder run too freely, and burns the tinning off the soldering tips. Poor fluxing prevents the solder from amalgamating with the pieces and, hence, they will not join. Platinum, silver, gold, tinned sheet iron, and most other metals may be soldered but it has thus far been practically impossible to solder aluminum commercially. A number of processes have been devised for soldering aluminum but none of them are in very general use and most of them have been failures.

Brazing

Brazing is a process similar to soldering, the main difference being in the use of a harder filling material and one requiring a higher melting temperature. Gold, silver, copper, brass, and iron may be brazed and the process consists broadly in melting a filling material called "spelter" into the joint to be made. The spelter used for brazing varies with the nature of the work, the hard alloys consisting of copper and zinc, and the soft ones consisting of tin and copper, or tin and antimony. Hard spelter gives a stronger joint than soft spelter, of course, but in all cases the spelter must amalgamate with the metal joined in order to make a good joint.

Flux. The flux for brazing is made of borax or boracic acid, the latter being cheaper. Borax will swell up under the flame, blister, and run off unless the water of crystallization has been

burned out, whereas good borax will melt and run over the surface and clean it nicely. The surfaces should be cleaned carefully before brazing, the same as when soldering. Salammoniac, zinc chloride, salt, and various acids have been tried as brazing fluxes but none are so good as borax.

Equipment. The equipment required for brazing consists principally in having suitable means for heating the pieces to the proper temperature and a supply of the proper spelter. Beyond this there are many good things which assist in making brazing easier, such as special fixtures for holding the pieces while working, torches or furnaces of various sizes, and similar things which will suggest themselves to the worker from time to time. As stated, the things which are necessary are but few in number.

A torch is used when brazing small and moderate-sized pieces and a forge or furnace such as shown in Fig. 42, for heating large pieces. Gasoline or kerosene give more heat than gas, but a blacksmith's forge provides the best means for heating and cooling. The pieces to be brazed should be preheated, brazed, and cooled slowly, and care must be taken to see that any sulphur in the coal or any soot from the fire is kept away from the pieces to be welded. The parts should not touch the fuel. A reducing or nonoxidizing flame is required and the brazing is done at a high temperature. Iron and steel require almost a white heat and a Bunsen flame with a blue cone is generally used.

Fig. 42. Double-Jet Brazer
Courtesy of Turner Brass Works

Process of Brazing. The process of brazing varies according to the work to be done and is a somewhat more expensive and complex process than soldering. The surfaces to be brazed must be cleaned, of course, by scraping and washing, and then brushing with a wire brush. The borax or other flux is then applied and the pieces placed together ready for brazing. The tighter the parts are clamped, the stronger will be the joint. If no regular furnace is available, a rough

one should be built of bricks, Fig. 43, so as to enclose the articles on all sides but one, in order to retain the heat.

There is considerable variation in the practice of brazing, for the details of the operation depend upon the nature of the work to

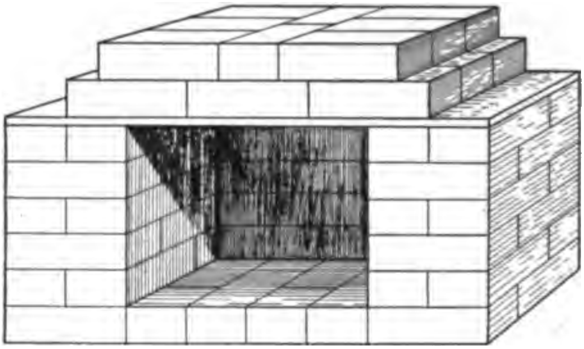


Fig. 43. Temporary Brick Furnace for Brazing

be done, the size and the shape of the pieces, the material, etc. For the production of pieces in quantities, especially articles made of sheet metal, the spelter is melted in a ladle or pot and the pieces are dipped therein. In this operation the flux is floated on top of the spelter and the pieces are cleaned before dipping. The flux then does its work as the articles are dipped into the spelter.

For castings and other articles which require brazing, but which cannot be dipped because of the nature or location of the joint, it is customary to prepare the joint as previously described; place the

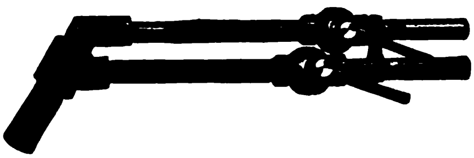


Fig. 44. Hand Gas Torch for Brazing
Courtesy of Turner Brass Works

pieces together in proper position; build a temporary furnace around the piece, or place it in a suitable furnace; and then heat it by playing a flame on it. Gas torches with air blast, Fig. 44, make good heaters and the temperature may be regulated to suit the size

of the piece. When the article is properly heated and fluxed, the spelter will flow into the space between the parts, wet both surfaces fully, and make a tight joint.

Care should be taken to see that the article does not cool too quickly, especially iron castings, or unequal shrinkage will cause cracking. Heating should also be gradual to prevent unequal expansion for the same reason and burning must be avoided. Sometimes the pieces may be covered with graphite paint, except where the brazing is to be done, thus preventing the flame affecting those parts. This is especially important when brazing brass as it should prevent the zinc from volatilizing and passing out of the alloy, thus leaving it spongy. The brazing of gold and silver requires special alloys; this is usually put in the hands of a jeweler and, as it is generally a small job, it is usually done with a blowpipe.

Use of Brazed Joints. Brazed joints are often stronger than the original metal but are not so good as welded joints, although they are cheaper and easier to make. Cast-iron pieces will not break at the joint, when properly brazed, and such joints are about 15 per cent stronger than the casting. One of the greatest objections lies in the possibility of leaving flux or rust in a brazed joint and weakening it. There is also danger of electrolytic action between the spelter and the material brazed and brazed joints do not always stand up well under repeated shocks. On the other hand, on articles of steel there are probably more joints made by brazing than by any other process (except riveting), thus proving it to be a generally reliable commercial process.

RIVETING

Riveting is not a welding process but it deserves a place in any treatise on the art of joining metals because it is in such general use for that purpose. While it is true that riveting is rapidly being superseded in many cases by various welding processes, it will never be abandoned entirely and is therefore worthy of consideration here.

Details of Process. The process of riveting consists in joining pieces of metal by means of rivets, which are short pieces of soft bars or rods with a head on one end. They are usually made of the same material as the pieces to be joined, such as steel, iron, copper, brass, aluminum, etc., and are used hot or cold as may be required. Steel

and iron rivets for joining plates or other pieces of the same materials are usually red-hot when used; so they are easier to head over and will draw the pieces tightly together as they shrink while cooling. Rivets of softer materials are used cold.

Shapes of Rivet Heads. The more common forms of rivet heads are shown in Fig. 45, wherein *A* shows a plain round head on both sides of the plates; *B* shows a round head on both ends but with the plates slightly countersunk to form a shoulder under the head for added strength; *C* shows a plain rivet with a pointed or steeple head above and a rose, or cone, head below; *D* shows a countersunk head above and a round head below; *E* is similar to *D* with the lower plate countersunk to give a shoulder under the head, and *F* has countersunk heads both above and below. Round heads are most com-

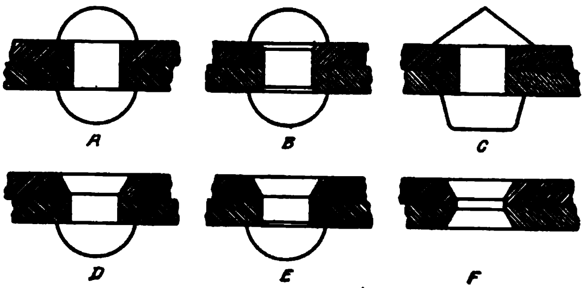


Fig. 45. Types of Rivet Heads

monly used; steeple and cone heads are used for boilers; and countersunk heads are used only when necessary for finish or to avoid some other attachment.

Tank and Boiler Work. When making tanks, pipes, boilers, or other articles of steel plates, the first operation is to shear the plates to the desired size and then trim the edges. Rivet holes are then punched or drilled near the edges of the plates, these being of the proper size and quantity for the strength demanded. If the article to be made is cylindrical in form—such as a boiler—the plates must be bent to the proper shape by being passed through rolls after the rivet holes are made. A few bolts should be put into some of the holes, after the plates have been placed in proper position for riveting, in order to hold the plates in place until the rivets have been driven and set. These can then be removed and rivets substituted

for them. Rivets always used to be headed over by hand but machine riveting has been adopted now for nearly all work done in shops and a large part of that done in the field; it is much to be preferred on account of its uniformity.

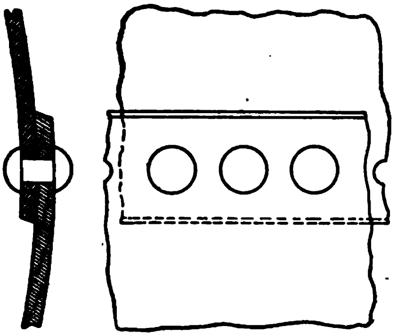


Fig. 46. Single-Riveted Lap Joint

Types of Joints. The joints used in riveting plates are either of the lap or of the butt type; a lap joint is one where the plates are laid on top of each other, and a butt joint is one where the plates come together edge to edge with another plate covering the joint. The added plate is known variously as a "welt strip", "cover plate", or "butt strap"; two of them are used for extra heavy work. Where the plates lap over and a single row of rivets is used, the joint is known as a "single-riveted lap joint", Fig. 46, this being the commonest and most used form of joint and being entirely suitable for the majority of seams.

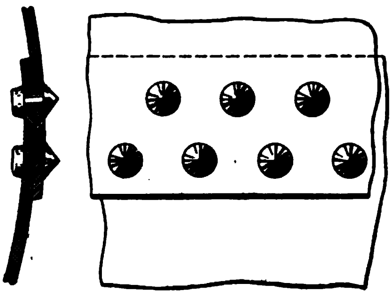


Fig. 47. Double-Riveted Lap Joint

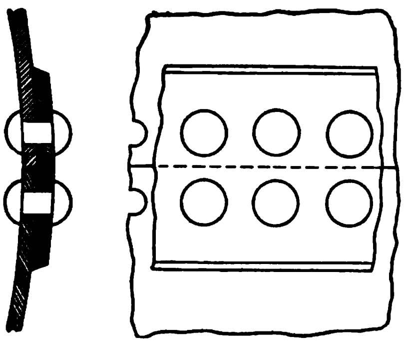


Fig. 48. Butt Joint with Single Strap

Where the plates lap further and two rows of rivets are used, as in Fig. 47, it is called a "double-riveted lap joint", this type being used for moderately heavy plates or for high pressures. If the plates are brought together edge to edge and a cover plate put on one side as in Fig. 48, it is known as a "butt joint with a single strap" and is frequently used for the lengthwise seams of tanks or boilers. For very high pressures and heavy plates the custom

is to use a "butt joint with two welt strips", two rows or three rows of rivets being used through both plates and strips, and an additional row passing through the inner strip and plates only, Fig. 49. Other types of joints are sometimes used but these are the most common and most easily made. When a single butt strap is used, it is about $1\frac{1}{8}$ times the thickness of the plates but when two are used, the outer one is of the same thickness as the plate and the inner one is about $\frac{3}{4}$ the thickness of the plate. Butt joints should be used for plates over $\frac{1}{2}$ inch thick, two strips being used. Lap joints are used for the girth or circumferential

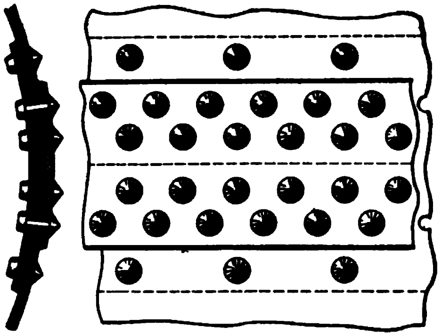


Fig. 49. Butt Joint with Two Welt Strips

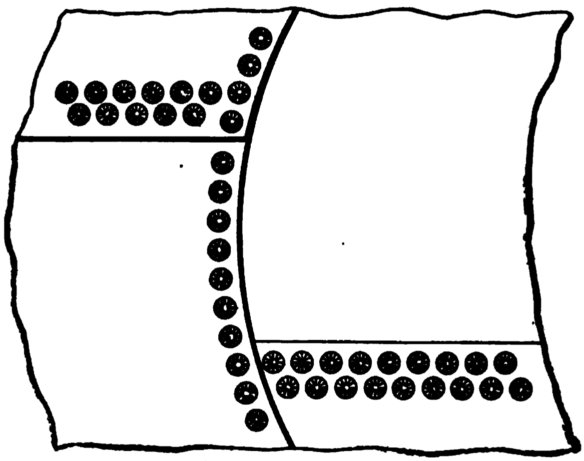


Fig. 50. Typical Boiler Shell Showing Method of Riveting

seams and butt joints with one or two straps for the longitudinal seams, Fig. 50. The lengthwise seams of a boiler have the greatest strain on them.

Strength of Joints. The strength of a riveted joint depends upon the materials used, the diameter and number of rivets, and the

way in which the strain is applied to the rivets. The plate may break along the line of the rivet holes; or the rivet itself may shear off; or the plate may shear out in front of the rivet or it may simply crush in front of the rivet. Rivets should never be used where they are subjected to a tensile or pulling strain as their greatest strength is when in shear or crosswise strain. If they can be placed in double shear through using butt joints and butt straps on both sides, they work still better. Plates seldom shear in front of the rivets but sometimes they break along the line of the rivets and rivets sometimes shear off or pull out under heavy strains.

Table I gives the figures used by several boiler and tank makers for riveted joints and applies to single-strap butt joints and lap joints. The "efficiency of joint" indicates the relative strength of the joint and the rest of the plate, and is given as a ratio. The

TABLE I

Efficiency of Single-Strap Butt Joints and Lap Joints

Thickness of Plate, Inches	Diameter of Rivet, Inches	Diameter of Hole, Inches	Pitch		Efficiency of Joint	
			Single, Inches	Double, Inches	Single	Double
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	2	3	.66	.77
$\frac{5}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$2\frac{1}{16}$	$3\frac{1}{8}$	.64	.76
$\frac{3}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$2\frac{1}{8}$	$3\frac{1}{4}$	.62	.75
$\frac{7}{16}$	$\frac{13}{16}$	$\frac{7}{8}$	$2\frac{3}{16}$	$3\frac{3}{8}$	.60	.74
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{15}{16}$	$2\frac{1}{4}$	$3\frac{1}{2}$	.58	.73

"pitch" indicates the distance between the centers of the rivet holes in the plate.

When laying out plates and riveting, care should be taken to see that the various longitudinal seams do not come in line with each other, but that they are offset, or staggered. The inner plate of the longitudinal seam should be hammered thin at the edge where it comes to the circumferential or girth seam so that the rivets can draw the plates tightly together at all points; otherwise there will be leakage.

When rolling iron and steel plates, there is a fiber formed lengthwise of the plates in the direction they are rolled and, when making boilers or tanks, it is important that this fiber should run around the boiler in the direction of the girth seams to get the greatest strength. When ordering plates, it is customary to give that

dimension first which indicates the way the fiber must run. When plates are to be flanged or turned up around the edge, as for heads of tanks or boilers, the curve at the corner should have a radius equal to at least four times the thickness of the plate and the material should be of the best quality. Marine boilers sometimes have the edges of the shell flanged inward and a flat plate used for the head, but this method is more expensive than flanging the head for most work.

Calking. Calking is the operation of closing the edges of a riveted joint to make the plates fit tight and give a good joint. A round-edged tool, Fig. 51, is driven against the edge of the overlapping plate so as to make it flow down against the other plate and close up any space between them at the edge. Unless this operation is properly done, however, the seam may be opened instead of closed and the joint be made worse than before, and this is one of the operations that is being superseded by electric welding. Electrical calking is done by using a metallic electrode and depositing metal along the edges of the plates by means of the heat from an arc, thus covering the joint and drawing the two plates together, Fig. 81.

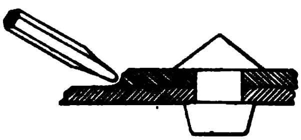


Fig. 51. Calking a Riveted Seam

Riveting Tools. The tools required for riveting consist of hammers, calking tools, rivet sets for forming the heads, rivet heating furnaces, punches, shears, drills, drifts for drawing the holes in line, and, in some cases, pneumatic or hydraulic riveting machines. For the average small shop it will be sufficient to have hammers, heaters, shears, punches, and drifts, with a set or two for the heads. The use of drift pins for drawing the holes in line is very common practice on cheap work but should never be done on a good job as it distorts the holes and prevents the rivets from filling them. Punched holes should not be used for good work as this operation is liable to injure the plates. Drilling is preferable, especially for steel plates.

ELECTRIC-ARC WELDING AND CUTTING

Historical. The use of the electric arc as the source of heat for joining and melting metals is one of the oldest applications of electricity and yet it was not developed to a commercially practical

point until within a comparatively few years. In 1786, Martinus van Marum published a book, in Leipzig, describing some early electrical experiments, and, in this book, he gave an exhaustive treatise on the melting of metals by means of the electric current. In 1810, Sir Humphrey Davy, the versatile English scientist, described some experiments made in London with various metallic bodies, and, in 1815, J. G. Children of Londen described a process for welding iron wire with the electric arc obtained from batteries. From then until now, the development of the art of electric welding has progressed steadily, so that today it stands as the most universal of all welding systems and is being adopted rapidly for all classes of metal manufacture and repair. The men who have done most to perfect electric-arc-welding processes are De Meritens, Bernardos, Olszewsky, Coffin, Zerener, Slavianoff, Howard, and a few others of lesser importance, and further reference to the processes developed by some of them will be made.

Characteristics of the Electric Arc. The electric arc has probably been given more careful study and investigation than any other electrical phenomenon and yet there is comparatively little exact knowledge available regarding some of its most important characteristics. The exact temperature of an arc has never been determined although the most refractory substances may be melted in its vapor and, since the vapor is so hot, it is a very efficient source of heat. The temperature has been variously estimated at from 2000 degrees centigrade by some scientists up to 6000 degrees centigrade by others, but the temperature generally accepted as correct is about 4000 degrees centigrade. As long ago as the year 1840, Grove discovered that the current flows more easily from metal to carbon than in the reverse direction and that the current through an arc is greater, when passing from an easily oxidized metal to one that is not, than when flowing in the reverse direction.

The explanation of this is comparatively simple. The conductivity of an arc depends largely upon the kind of vapor in the arc and, to some extent, upon the ease with which the cathode (negative electrode) can be kept at a high temperature. If the anode (positive electrode) gives off a conducting vapor when heated, this vapor will help the conductivity of the arc. In the arc-welding

systems in commercial use today, the arc is drawn between metal and carbon, or between metal and metal and, since the positive electrode or terminal of an arc reaches a higher temperature than

Fig. 52. "Striking the Arc"
Courtesy of Westinghouse Electric and Manufacturing Company

the negative electrode, it is more efficient to use the article worked upon as the positive electrode of the arc. Since iron is more easily vaporized than carbon, the current flows more easily from iron to carbon than the reverse, because there is more iron vapor than

carbon vapor in the arc. This is proved by the fact that it requires more voltage to send a given current through an arc between carbon electrodes than between iron ones. It is also important that the negative electrode be kept at a high temperature and the usual practice of having the negative electrode small (due to the use of a wire or carbon pencil) makes this easily possible.

ELECTRIC WELDING PROCESSES

General Features. The process of welding or cutting with the electric arc is possible with nothing more than a source of current at a suitable voltage, some means for regulating the amount of current flowing, and an electrode. Practice has shown, however, that certain other devices are necessary, if satisfactory welding is to be done; and it is the determining of these devices and their

Fig. 53. Arc-Welding Lug on Steel Casting
Courtesy of Westinghouse Electric and Manufacturing Company

proper uses that constitutes the main differences in the various processes used today. In order to do welding or cutting with the arc it is necessary first to connect the work to the positive side of the power-supply circuit and the electrode to the negative side of the circuit, by means of wires or cables, and to insert a regulating resistance in either of these circuits to limit the current flowing to the proper amount. The negative electrode should then be placed in contact with the work and quickly withdrawn, thus establishing the arc, Fig. 52, which provides the temperature required. As the metal soon begins to melt the work may begin at once.

In general, electric-arc welding consists in using the heat of the arc to fuse or melt the filling material into the place to be filled,

Fig. 54. Operator Using Metallic Electrode
Courtesy of C & C Electric and Manufacturing Company

Fig. 55. Operator Using Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

Fig. 53, although the article worked upon may be melted down sufficiently to fill the space, if it is large enough at the point to be welded. Two methods or processes of using the arc for welding are in commercial use today, these being the "metallic" and the "graphite" processes. The metallic welding process, Fig. 54, consists in using a piece of wire as the negative electrode of the arc and fusing it into place; the graphite process, Fig. 55, consists in using a piece of carbon or graphite as the negative electrode and fusing a piece of metal into place by the heat of the arc, similar to a gas process. The graphite process is always used for cutting, a slot being melted through the piece to be separated. There is also a third system which will be described later, but it is not used much in the United States.

Benardos System. The Benardos system of electric-arc welding is based upon the use of a carbon pencil as the negative electrode and the article worked upon as the positive electrode, using for the purpose a continuous, or direct, current at a moderate voltage (usually from 60 to 70 volts). After the arc is established by touching the electrodes together and withdrawing, a piece of the filling material in the form of a "melt bar" is fused into place by the heat of the arc. Any metal, which does not volatilize or burn up too easily at the temperature obtained, may be welded by the Benardos process and this process is the best to use for cast iron, the copper alloys, and aluminum. When using the graphite pencil, it is necessary to give the hand a sort of rotary motion in order to cause the arc to play about over the surface of the job and prevent burning, for the arc never stops melting the metal so long as it exists. This motion also has the effect of causing any slag or impurities on top of the molten mass to flow off to one side, instead of remaining in the weld and spoiling its quality, and of distributing the heat more

Fig. 56. Siemund Hand Electrode Holder
Courtesy of Siemund Wenzel Electric Welding Company

uniformly over the piece welded. When cutting with the arc, the article should be so placed that work can begin at the top and progress downward across the face of the piece.

Slavianoff System. The Slavianoff system of electric-arc welding is based upon the use of a metallic pencil, Fig. 56, as the negative electrode, and the article worked on as the positive electrode, and the use of a continuous current at low voltage. After the arc has been established by touching the electrodes together and separating them, as before, the negative electrode itself begins to melt and thus forms the filling material. This system is more successful for work with iron and steel electrodes than with the other metals, although many of them may be used where high-class work is unnecessary. The main application of this system has been to sheet-steel work, the metal electrode being deposited along the joint to be made and tying the two plates together so that they form practically one piece. This process may also be used for building up worn or missing pieces, filling holes, etc. The current required for the Slavianoff process is much less than that for the Benardos process but it is much slower for operations involving the placing of any very large amounts of metal quickly. The successful development of the Slavianoff system has been the principal cause for the recent rapid spread of electric-arc welding in the industries.

Fig. 57. Type of Zerener Welding Unit
Courtesy of Westinghouse Electric and Manufacturing Company

Zerener System. The Zerener system consists in having the two electrodes made of carbon and mounted in a frame which holds them at an angle with relation to each other and to the work, Fig. 57. The arc is drawn between them and is then deflected downward by a magnet and used in the same way as a gas flame. The apparatus for holding and feeding the carbon pencils is so bulky and complicated that this system has not been used in America to any great extent, although it is in use in several plants in Germany. The nature of the apparatus is such that large amounts of current cannot be used; so it is limited to comparatively light work. The weight

and size of the holders for even moderate-sized work are such that they must be suspended from above by ropes and moved about over the work, although small holders for use in one hand have been developed for holding the lightest articles. The advantage claimed for this system is that the arc is controlled by a magnet and that finer work can be done.

ELECTRIC WELDING EQUIPMENT

Simple Equipment Wasteful. The equipment required for electric-arc welding depends largely upon the nature of the work to be done but, of course, the most complete apparatus does the best work, as in the case of any other sort of apparatus. The most ele-

Fig. 58. 900-Ampere Welding Generator with Collector Rings at Each End for Taking Off Alternating Current
Courtesy of C & C Electric and Manufacturing Company

mentary equipment consists of a barrel of water with two iron plates in it (using the resistance of the water to reduce the amount of current flowing) and an electrode holder, with some cables to connect the parts to the power circuit. This system can be used for cutting and for welding where roughness and uncertainty of results are no disadvantage. The current is varied by varying the space between the plates in the water barrel but this system is very wasteful and inefficient because the line voltage (usually 220 volts in shops and 550 volts for street railways) must be cut down to that required for welding (about 25 volts in the arc); this is done by dissipating the unused energy in the form of heat in the water. Sometimes resistances, made up of cast-iron grids, Fig. 60, are used instead of the water

barrel, but they are more expensive and just as inefficient. This grid resistance is cut into and out of circuit by a series of switches.

Advantages in Low-Voltage Generators. The use of dynamo-electric machines of low voltage, Figs. 58 and 70, instead of resistances as just described, is preferable because of their higher efficiency and the better voltage regulation obtained. Fig. 59 shows a typical wiring diagram for the low-voltage equipment. It is well known among electrical men that a properly designed motor-generator set gives the best regulation of voltage and, when the generator is properly compounded, we have the ideal apparatus for electric-arc-welding. The leading systems in general use today consist of motor-generator sets with suitable control apparatus for motor, generator, and the welding and cutting circuits.

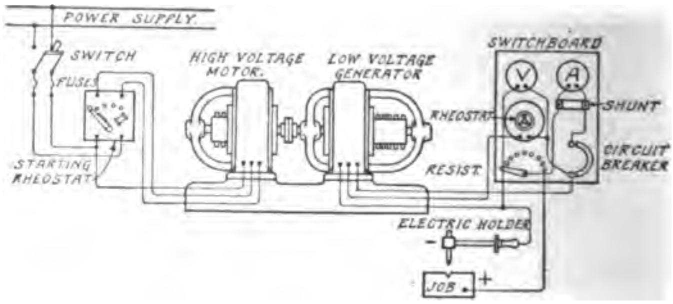


Fig. 59. Elementary Low-Voltage Arc-Welding Equipment

Single unit machines such as dynamotors, synchronous converters, etc., are also used, although the voltage regulation and current control are not quite so good as with motor-generator sets. For working with the graphite electrode and for the heavier classes of metallic electrode work they are all right, and a large number of them are in use in foundries, ship yards, railway shops, etc. A few of them are also being used in lighter work where the total load is not such as to cause a drop in voltage, and they make fine portable outfits because of their small size and light weight.

There are at present only seven companies of importance in the United States offering electric-arc-welding outfits, six of which use low-voltage generators and the seventh furnishing iron-grid resistances to reduce the voltage to that required for welding. The C & C Electric and Manufacturing Company has been in the field 11 years;

Westinghouse Electric and Manufacturing Company, 9 years; General Electric Company, 8 years; Lincoln Electric Company, 5 years; and the Burke Electric Company is just entering the field. These are the only companies manufacturing arc welders, although the Siemund-Wenzel Electric Welding Company is having apparatus made for it by the Crocker-Wheeler Company; the Welding

Fig. 60. Portable Electric Welder in Action
Courtesy of Indianapolis Switch and Frog Company

Materials Company has its apparatus made by the Triumph Electric Company; and the Indianapolis Switch and Frog Company makes a resistance system, as stated. Each of these companies offers apparatus on the strength of some peculiarity of the controlling apparatus for the welding circuits or certain features of the welding machines.

Indianapolis Track Welder. The Indianapolis Track Welder, Fig. 60, consists of a group of iron resistance grids mounted in a framework on a four-wheeled truck, with means for making connection with the trolley wire to get current. It is used almost entirely for repairs on street railway tracks. The control device consists principally of a set of switches for varying the number of grids in series with the arc, an electrode holder and cables. The Slavianoff system is used for most operations, although the Benardos system may also be used. Owing to the low efficiency of operation they have not been adopted for use in industrial plants, but the cost is comparatively low and street railway companies do not seem to object to the enormous waste of energy incident to their use.

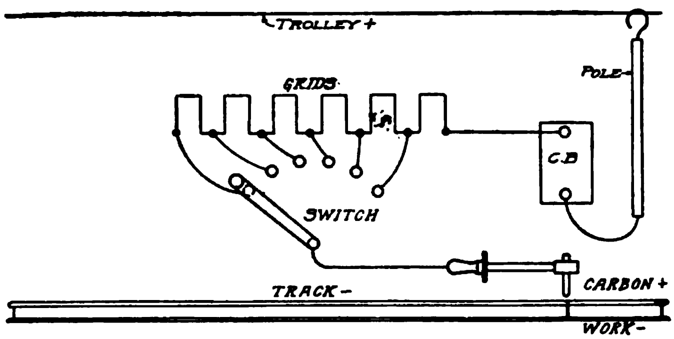


Fig. 61. Wiring Diagram Showing Principal Features of the Indianapolis Track-Welding System

The diagram of connections, Fig. 61, shows the relation of the various parts of this equipment and the switches for varying the current by cutting in or out the grids of the resistance. The nature of this system, as with water barrels, is such as to necessitate a separate outfit for each operator in order that he can adjust his current to suit the work in hand without interfering with the other operators.

Westinghouse Arc Welder. The equipment produced by the Westinghouse Electric Company consists of a motor-generator set with switchboards for controlling the machine and the welding circuits. The generator is a 75-volt compound-wound direct-current dynamo and is direct-coupled to a motor of proper capacity and suitable for operation from the power circuit available. Being

a constant-potential generator, several operators may work from it at once if proper resistances and switches are provided for each circuit, and work may be done by either the Benardos or Slavianoff processes. An overload circuit breaker is provided for the protection of the generator from the effects of injurious overloads after welding has started.

With this apparatus various classes of welding and cutting may be done and the positive line is connected to the work and the negative to the electrode holder in the usual manner. The amount of current required for the work in hand is regulated by a series of

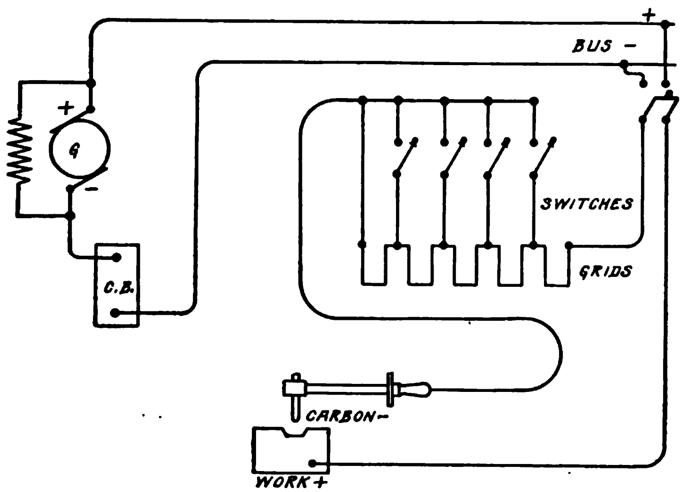


Fig. 62. Wiring Diagram for Westinghouse Arc Welder

switches which cut in or out sections of an iron grid resistance, and a small portion of the resistance bank is left in circuit continuously to steady the arc. This apparatus has been used almost entirely for graphite cutting and welding until recently when means were provided for using metallic electrodes also. Fig. 62 shows the principal elements properly connected for a single operator, and more circuits would involve the addition of the extra switches, resistances, and electrode holders for each of them. The apparatus for controlling the machine and the welding circuits is mounted on switchboard panels stationed near the motor-generator set.

Lincoln Arc Welder. The Lincoln Electric Company make both motor-generator sets and single-unit machines for welding

equipments, both being similar in operation to the Westinghouse outfits just described. The wiring diagram shown in Fig. 63 shows the general connections. The single-unit machines are made as synchronous converters for use on alternating-current circuits or as dynamotors for use on direct-current circuits. The Lincoln dynamotor differs from others in that there is but one commutator, and the outgoing or generator circuit is taken from two extra brushes located between the motor brushes in the proper position to give current at the proper voltage. The amount of current is varied by varying the strength of the interpoles through switches and by the length of the arc. Resistances are used for varying the current

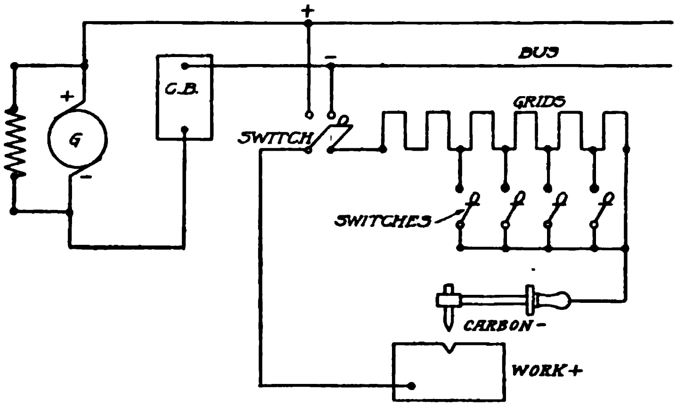


Fig. 63. Wiring Diagram for Lincoln Arc Welder

from the alternating-current converters, and also from the motor-generator sets in the usual manner.

Switchboards are provided containing the apparatus for controlling the welding machine and welding circuits, and an overload circuit breaker is provided to protect the generator from dangerous overloads while working. The overload circuit breaker must be closed by hand if opened. The voltage regulation of the single-unit machines is not quite so good as with their motor-generator sets, of course, but work can be done by either the Benardos or Slavianoff process.

Siemund-Wenzel Welding System. This system is based upon the use of a single shunt-wound direct-current generator for each welding circuit, Fig. 64, and operates on the Slavianoff process.

The principal feature of this system lies in having the generator operating at full load all of the time, and using the current in the

Fig. 64. Single Welder Siemund-Wenzel Unit

arc when welding or dissipating the energy through a resistance in the form of heat when not welding, Fig. 65. The circuit is thrown

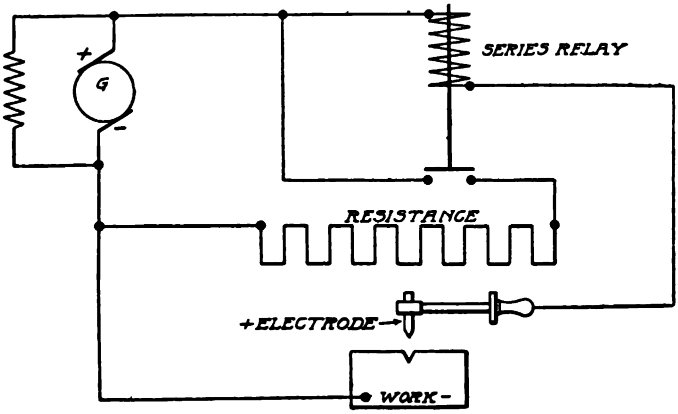


Fig. 65. Wiring Diagram for Siemund-Wensel System

from the arc to the resistance by means of a solenoid switch, and only one man can work from each machine at one time.

The current is varied to suit different jobs by varying the voltage at the generator, but the current also varies with variations of arc length and tends to vary the amount of metal deposited. This company also uses an electrode holder with a coil embodied in the handle in such a way as to set up a magnetic field around the metallic electrode and arc, on the theory that it helps in depositing the molten metal in the weld, especially or overhead work. This is a doubtful

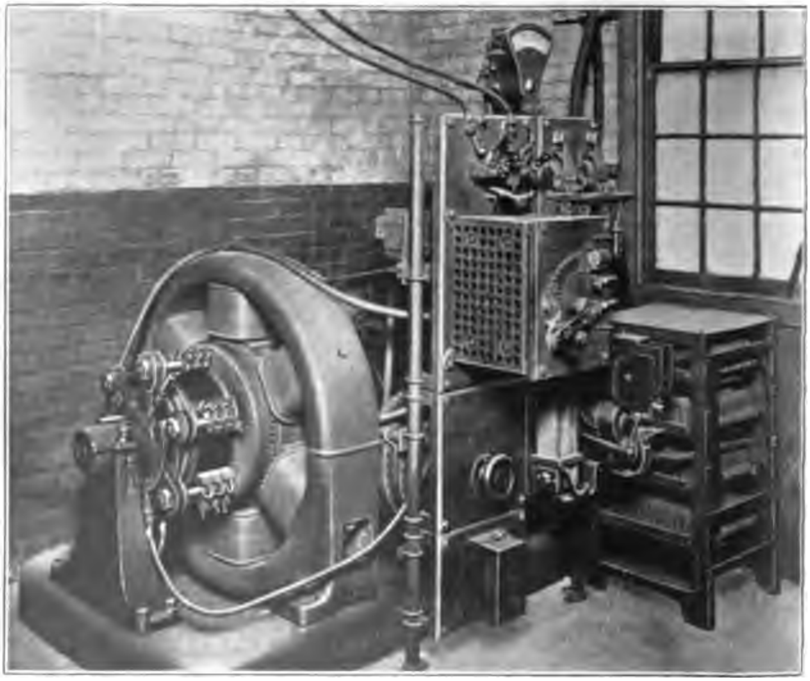


Fig. 66. Arc Welding Set with Automatic Overload Relay
Courtesy of General Electric Company

advantage because molten iron and steel are non-magnetic, and in fact are practically so at temperatures as low as 700° centigrade.

General Electric Arc Welder. The welding equipment developed by the General Electric Company, Fig. 66, consists of a compound-wound low-voltage direct-current generator, similar to those previously described, direct-coupled to a motor to suit the power supply, together with a switchboard containing the necessary devices for controlling the machine and the welding circuits. These equip-

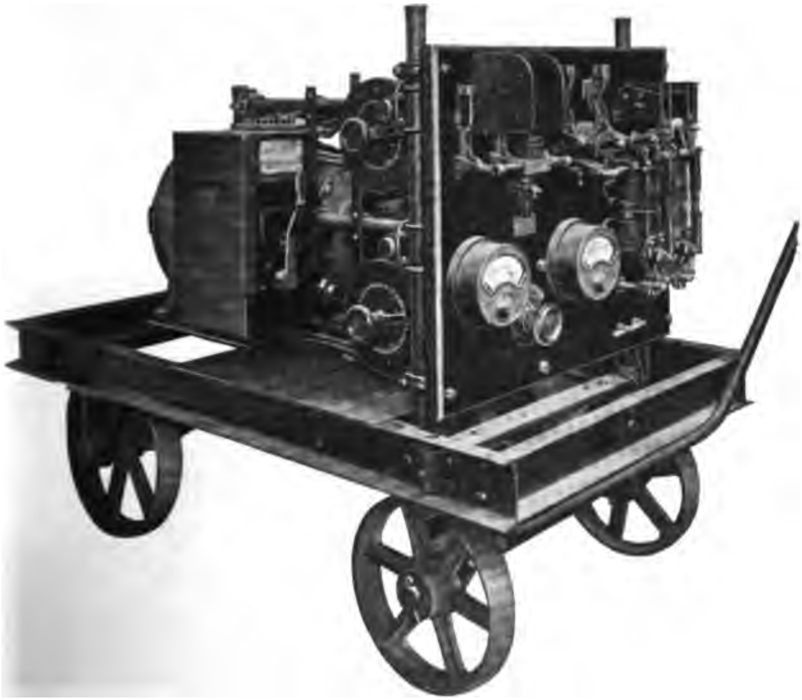


Fig. 67. Portable Welding Outfit
Courtesy of General Electric Company

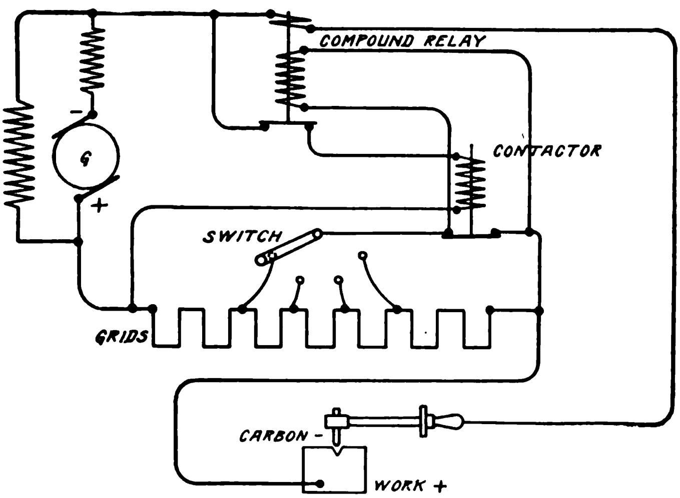


Fig. 68. Wiring Diagram for General Electric Welding System

ments are made in portable form also, Fig. 67, with the entire outfit mounted on a truck.

By reference to Fig. 68, it will be seen that the current flows from the positive side of the generator to the work through a bank of resistance grids; thence through the arc, electrode, relay, and back to the generator, negative side. The contactor opens and inserts resistance in case the relay is actuated by an overload, and the amount of current required in the arc for welding is varied by a multiple contact switch which cuts in or out sections of the grid resistance. Several men can work at once from machines of this type

Fig. 69. Operator Using Graphite Electrode on Medium Work
Courtesy of General Electric Company

because of using the constant-voltage system, by adding enough circuit-controlling relays and contactors. The use of the overload relay described prevents injurious overloads on the generator, although the only limitation to current flow in the individual welding circuits of multiple-circuit equipments lies in the resistance in use at the time. In Fig. 69 is shown an operator using the graphite electrode on medium work.

C & C Electric-Arc-Welding System. The C & C system of electric arc welding has been developed during a longer period than any of the others, because the C & C Company is the pioneer in

that field in America and, consequently, has its control system developed to a higher degree and protected by numerous patents. The welding machine consists of either a single-unit machine or dynamotor for use on direct-current circuits, or a low-voltage compound-wound direct-current generator of high overload capacity direct-connected to a motor of proper size and suited to the power supply, both machines being mounted upon a substantial cast-iron base as indicated in Fig. 70. For controlling the motor and generator, a switchboard is supplied which may be mounted in any convenient position with relation to the machine and connected to the power circuit. On this panel are mounted the necessary instruments and switches for the welding machine and motor, and the apparatus for

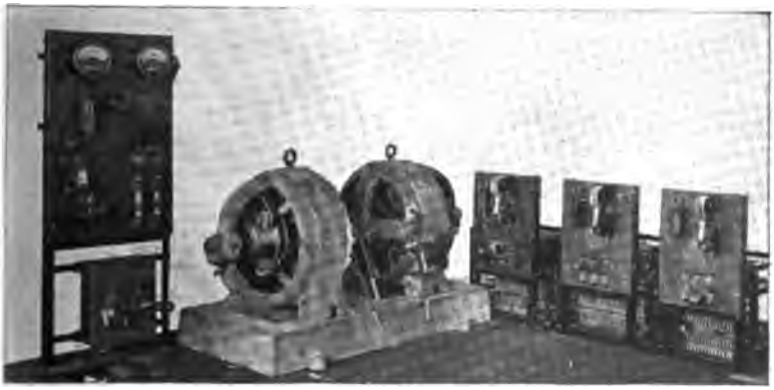


Fig. 70. 300-Ampere Welding Set with Control Panel and Auxiliary Welding Panels
Courtesy of C & C Electric and Manufacturing Company

controlling the welding circuits is usually mounted upon separate smaller panels, although for portable equipments or single-circuit outfits everything is mounted on the main switchboard panel.

Each welding-circuit control panel contains one of their patented automatic control outfits, and means are provided for preventing a rush of current when drawing the arc as well as for inserting a protective resistance to reduce the current in case of overload when using the graphite arc. By this means the thinnest metal, Fig. 71, or the heaviest castings, Fig. 72, may be welded safely and smoothly with equal facility, and the operation of the controlling devices is so entirely automatic that the operator does not have to go to the switchboard and close circuit breakers or other devices after once

starting work. This system of welding has been developed for working by either the Benardos or Slavianoff process.

By referring to the diagram of connections, Fig. 73, it will be seen that the current flows from the positive side of the generator to

Fig. 71. Miscellaneous Pipe Welds with Light Tubing
Courtesy of C & C Electric and Manufacturing Company

the job, through the arc, electrode and holder, resistance, overload and series relays, and back to the negative side of the generator. The diagram shows the positions of the various items before the arc is drawn, and it will be noted that all of the resistance is in series

Fig. 72. Broken Steel-Forged Crankshaft Welded with Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

with the electrode and other devices. The arc will, of course, be drawn between the electrode and the work in the usual manner, and it will be noted that the coil on the magnetic contactor is so connected as to be in shunt or parallel with the arc. When contact

is made between the electrode and work to establish the flow of current and strike the arc, the coil of the series relay will be energized and it will close and energize the coil of the magnetic contactor. The contactor will not close, however, until after the electrode has been removed from contact with the work and the arc formed, because that contact is of lower resistance than the coil in shunt with it. So long as the magnetic contactor is open, all of the grid resistance is in circuit and the flow of current is too small to burn

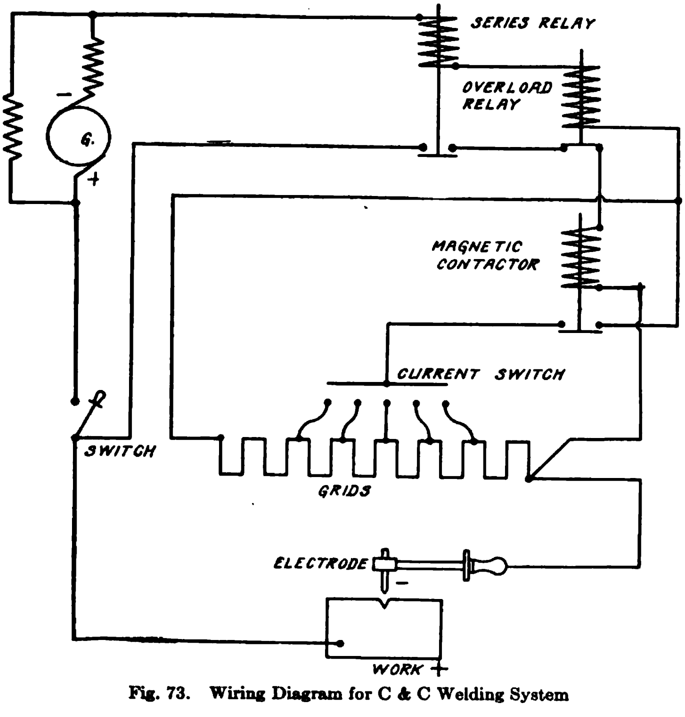


Fig. 73. Wiring Diagram for C & C Welding System

the work or overload the generator. As soon as the arc is drawn, that path becomes of higher resistance than the path through the shunt coil on the contactor, hence the magnetic contactor coil gets current enough to close the contactor and cut out resistance until enough current flows to suit the job in hand as predetermined by the setting of the resistance switch. In case of overload while working, the overload relay open-circuits the coil of the magnetic contactor and causes it to open and re-insert the entire resistance, cutting the current to the minimum without rupturing the arc.

Owing to the use of a separate panel for each welding circuit, it is possible to have as many operators working at once as conditions require, tapping the panels off the distribution circuit from the machine panel the same as would be done with so many motors from any other circuit. The only limitation is that the generator shall be of sufficient capacity to furnish the current required. Another feature of this system lies in the use of an automatically self-closing overload circuit breaker on the main control panel for the motor, thus restoring the motor circuit automatically after the

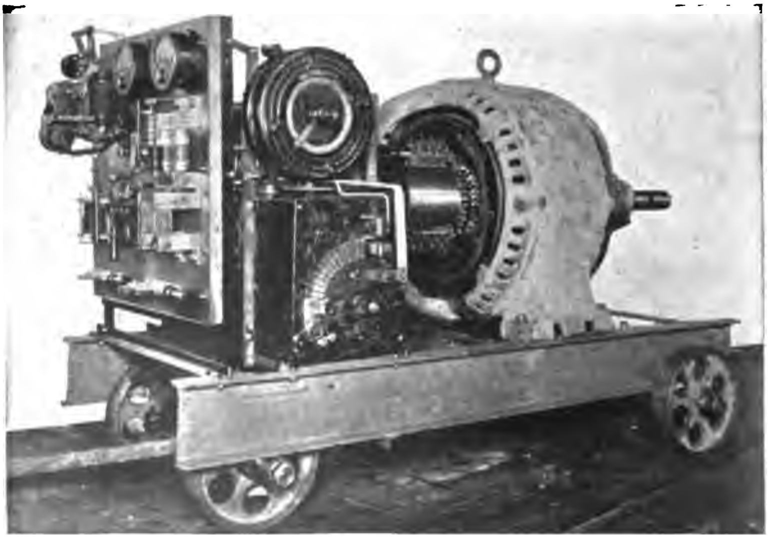


Fig. 74. 600-Ampere Portable Single-Unit Welding Outfit
Courtesy of C & C Electric and Manufacturing Company

overload on the welding circuit or generator is removed. These outfits are also made portable, as shown in Fig. 74.

In addition to the constant-voltage apparatus just described, the C & C Company also makes a variable-voltage welding outfit for use when but one operator is to work from the machine. This consists of a differentially-wound compound-generator driven by a suitable motor, with proper controlling devices mounted upon a switchboard panel. With this outfit work is done with as low as 12 volts drop in the arc and at a very high efficiency. The generator voltage varies automatically to keep the current constant at the predetermined value, regardless of the arc-length.

Welding Materials Company System. This company has recently brought out a machine to replace that formerly handled by them, based upon the use of a compound-wound generator of the variable-voltage constant-current type having an auxiliary exciter. This exciter is provided with a special differential winding, which changes the voltage supplied to the main generator field. Therefore, the action of the welding current in the end automatically regulates the voltage of the main generator so as to keep the current constant and at the predetermined value regardless of variations in the resistance of the welding circuit. The proper current for the work in hand is obtained by regulating the field of the machine before starting work, after which it is kept constant by the machine. Owing to the use of low voltage (usually between 10 and 20 volts with a maximum of 30 volts) the efficiency is considerably better than machines operating at higher voltages, and machines of this type are coming into greater use where but one man is to work from a machine. It is impossible to work two or more men at once from apparatus of this type, multiple-circuit outfits always being of the constant-voltage type with resistance in each circuit to vary the current. Variable-voltage generators are driven by suitable motors and have the controlling devices on switchboards in the usual manner. Of course, with this system, no resistances are required.

Burke Electric Welder. The equipment offered by this company has lately been placed on the market and consists of the usual low-voltage machine with welding circuits containing regulating resistances, similar to those described for the Westinghouse and Lincoln outfits.

Quasi-Arc-Welding Method. An English system known as the "quasi-arc-method of welding" has been used to a limited extent abroad, but has not been received very kindly in America because of the expensive electrodes used. This is based upon the use of wires or electrodes coated with a flux for preventing oxidizing.

Kjellburg System. The Kjellburg system is also based upon the use of a flux on the wire and the users of it make some very strong claims for it, but experience shows that work can be done satisfactorily without flux for every kind of welding. With both of the above types of electrodes, any of the apparatus described may be used.

WELDING OPERATIONS

Amount of Current Used. Welding operations are of various kinds and take different amounts of current, depending upon the nature of the material worked upon, the size and shape of the piece, and the sort of operation to be performed. For example, thin steel sheets require less current than thick ones; cutting requires a larger amount of current than welding, etc. As a general rule it may be said that metallic welding operations usually require from 50 to 150 amperes, although thin sheets may be welded with as little as 15 amperes and extra heavy ones may take 185 or 190 amperes; graphite arc welding, on the other hand, averages from 350 to 500 amperes, running from 100 amperes on small articles up to 600 amperes on heavy work. Cutting with the electric arc requires from 300 amperes on small sections up to 1000 amperes or more, the average job taking from 400 to 600 amperes. The nature of the equipment supplying the energy will affect the amount of current required to some extent, those with the best control systems being the most economical.

Plate Welding. The rate at which welding can be done depends upon the article to be welded, its size and shape, material, nature of weld, etc., Table II indicates the speed of welding seams in sheet steel.

TABLE II

Data on Steel Plate Welding

Thickness	Diam. Electrode	Amperes	Seam Welded
28 to 20 gage	18 B. W. G.	10 to 25	30 ft. per hour
18 gage to $\frac{1}{8}''$	$\frac{1}{16}''$ diam.	20 to 40	25 ft. per hour
$\frac{1}{8}''$ to $\frac{3}{16}''$	$\frac{3}{32}''$ diam.	30 to 60	20 ft. per hour
$\frac{3}{16}''$ to $\frac{1}{4}''$	$\frac{1}{8}''$ diam.	50 to 100	15 ft. per hour
$\frac{1}{4}''$ to $\frac{3}{8}''$	$\frac{5}{32}''$ diam.	75 to 150	10 ft. per hour
Over $\frac{3}{8}''$	$\frac{5}{32}''$ diam.	150 to 180	Variable

The figures given in the last column are only approximate, as they may easily be exceeded by an expert operator, but they give a fair average. These apply to seams made by butting the edges of the plates together and welding along in the space between them. The edges of the plates should be beveled sufficiently to allow the filling material to penetrate the full thickness of the plates, Fig. 75, or else a satisfactory weld will not result. Thicker plates than those

given may also be welded and the time will vary as the square of the thickness. This is based upon one-fourth of an inch as the standard because that is about the thickest plate which may be satisfactorily welded by going along the seam but once. For thicker plates it is necessary to go along the seam several times in order to fill the slot properly and the area of the slot increases approximately as the square of the thickness when a V-shaped groove is to be filled. When an X-shaped slot, or two V slots, can be formed by beveling the plates on both sides, then the time required to make the weld

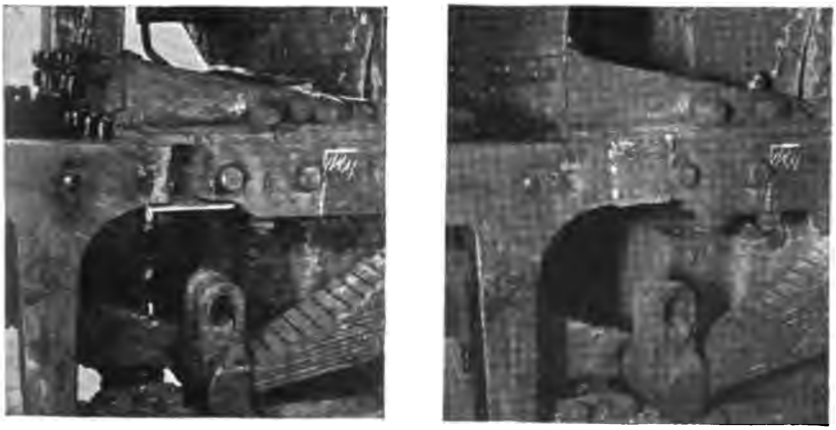


Fig. 75. Fractured Locomotive Side Frame Cut Out with Graphite Electrode and Welded with Metallic Electrode
Courtesy of C & C Electric and Manufacturing Company

is cut in two, and the rate of welding varies about in the same ratio as the thickness of the plates. The metallic electrode is used almost exclusively for steel plate and sheet welding, although the graphite electrode is sometimes used for heavy plates, when it is possible to work with the plates laid in a horizontal position, thus preventing the molten steel from running off.

Castings. When castings of iron or steel are to be welded, it is necessary to prepare a large enough space to work in; otherwise it will be impossible to join the pieces throughout their thickness. This is due to the fact that the filling material is not so liquid as that used with brazing and consequently will not flow in a small crack, but must be allowed to run easily into the space. With steel castings, and for some classes of small holes in large iron castings, the

metallic electrode may be used but, for most cast-iron pieces and very large steel pieces, it is necessary to use the graphite arc and a melt bar for the best results. For cast-iron welding it is desirable to preheat all but the smallest and simplest pieces before welding in order that the high-shrinkage factor of the metal will not cause cracks when the weld is cooling. It is also good to reheat after welding and allow the piece to cool slowly in order to insure a weld soft enough to machine. A good welding flux is also an advantage when making cast-iron welds in order to help raise the slag and improve the quality of the weld. Iron with about 25 per cent of silicon should be used for cast-iron welding, and steel with from 25 per cent to 40 per cent excess of carbon, manganese, vanadium, or

Fig. 76. Tank with Head, Flange, and Branches Welded in Place
Courtesy of C & C Electric and Manufacturing Company

other desired content should be used when welding steel castings containing the elements mentioned.

Copper and Aluminum. Copper and aluminum sheets, bars, and castings may be welded with the electric arc by using the graphite electrode and puddling in the filling. This operation is similar to welding cast iron and can be done only with the work laid in a horizontal position to prevent running. Owing to the necessity for using the graphite electrode instead of a piece of wire, it is evident that thin sheets cannot be successfully welded by this process. But sheets over one eighth of an inch thick have been welded, both of aluminum and copper, and castings as thin as one-fourth of an inch also. It is necessary to build a simple mold of clay around

the spot to be welded in order to hold the molten metal, but it is a very simple process and requires but the smallest amount of current which will melt the metal. Large amounts of current tend to burn the material and, if zinc is present (as in brass), it will volatilize or burn out and leave a porous and useless weld. The same thing applies to bronze alloys containing manganese, phosphorous, etc., but in a lesser degree. In other words, when welding alloys of any kind, it is necessary to use that current which is suited to the most volatile element in the mixture. The others will get heat enough to flow sufficiently for all practical purposes in most cases and experience will soon show any operator the best methods of handling any of the alloys.

Boilers and Tanks. Boilers and tanks offer one of the best fields for the application of the Slavianoff, or metallic welding, process and the adoption of this method in manufacturing, Fig. 76, as well as in repairing such articles instead of riveting them, Fig. 77, is proceeding very rapidly. Joints, which have been properly welded with a metallic electrode of suitable size and composition and with the right amount of current, will be stronger than riveted seams. If the joint is reinforced slightly by additional filling material, it will be stronger than the original plate but, even when ground flush with the thickness of the plates, it will show from 85 per cent to 90 per cent of the strength of the plates for thick stock, and up to over 95 per cent of the strength for thin stock. The various methods in use for welding the seams in tanks are shown in Fig. 78, those welded in two places being best for high pressure. These may be compared with the usual boiler riveted joints in Fig. 79. Since the strain on the longitudinal seams is double that on the circumferential seams, it is customary to lap-weld the side seams for strength. When the tank or boiler is intended for use under high pressures, it is better to lap all seams; then a butt strap is added to the side seams and welded at both sides and the center,

Fig. 77. Patch in Boiler with Seam Prepared for Welding

as indicated in one detail. The method of welding the head depends upon the shape of it, the convex head being the most common and flanged to slip inside the shell, and the welded seams are clearly indicated in the figure.

Boiler makers have been slower to take up electric welding

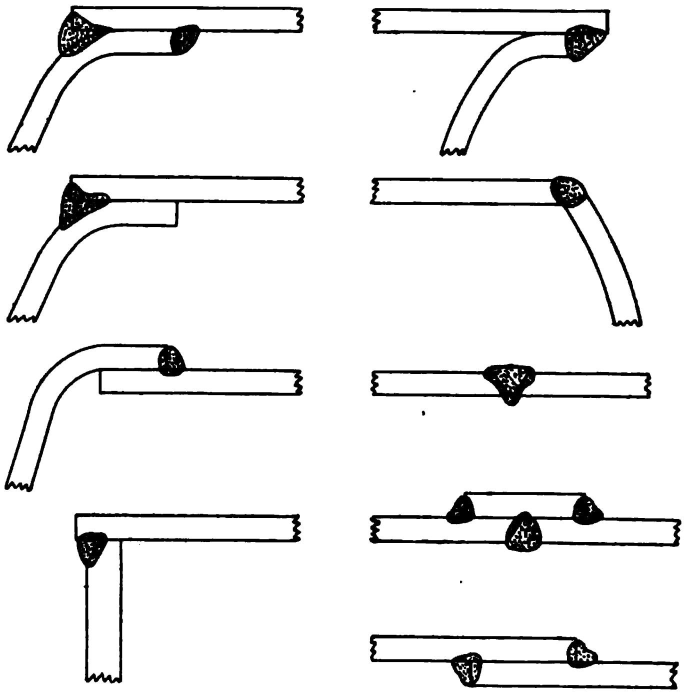


Fig. 78. Methods of Making Welded Seams in Tanks
Courtesy of C & C Electric and Manufacturing Company.

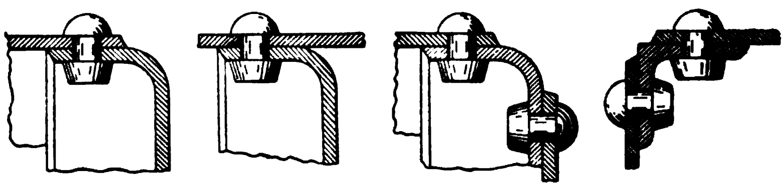


Fig. 79. Methods of Making Riveted Seams in Tanks

than have the tank makers because greater restrictions having been imposed upon them in the interests of safety and reliability, they are generally more conservative. But there is a strong tendency now to use electric-arc welding to an increasing degree and boards

of inspectors and other official bodies are more liberal each year. By welding along the edges of the plates instead of calking with a hammer, Figs. 80 and 81, the plates are tied together and strengthened as well as tightened and the job never has to be gone over again. If the plates are badly corroded, they may be re-

Fig. 80. Weld in Locomotive Fire Box
Courtesy of C & C Electric and Manufacturing Company

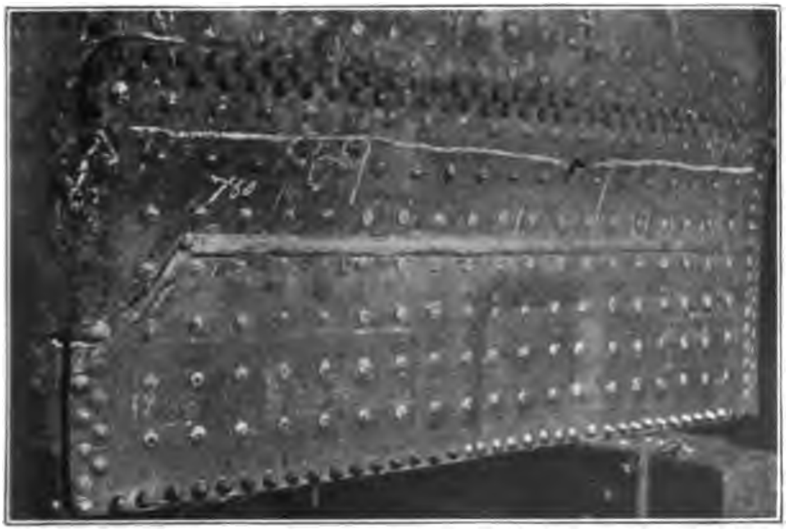


Fig. 81. Boiler Side Sheet Welded by Electric Welding Apparatus
Courtesy of The Boilermaker

Fig. 82. Electrically-Welded Boiler Flues
Courtesy of Railway Master Mechanic

stored to their original thickness or to a greater thickness and leaking rivets may be tightened by welding around the heads and fusing them to the plates.

Welding Boiler Flues. One of the most important applications of metallic welding is in the welding of flues of locomotive boilers, Fig. 82. The flue end is

expanded, beaded, and prossered in the usual manner, without the copper ferrule in the sheet, and then the edge of the bead is welded

Fig. 83. Broken Housing of Radial Drill
Courtesy of C & C Electric and Manufacturing Company

Fig. 84. Radial Drill Housing Welded with Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

Fig. 85. Broken Steel Wabbler for Rolling Mill Welded with Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

all around so as to attach it firmly to the sheet. This makes tubes and sheet one piece and eliminates leaking entirely, the life of the

TABLE III

Chemical Analysis of Iron and Steel Before and After Welding

Element	Sample No. 1, Iron		Sample No. 2, Steel	
	Per Cent Before	Per Cent After	Per Cent Before	Per Cent After
Silicon	0.009	0.003	.004	0.00
Carbon	0.015	Trace	.048	0.25
Sulphur	0.025	0.020	0.04	0.04
Phosphorus	0.068	0.043	0.08	0.07
Manganese	0.64	0.27	0.50	0.25
Iron (by difference)	99.108	99.664	98.86	99.39
Total percentage	100.000	100.000	100.00	100.00

weld being that of the tube itself. The law demands new flues every three years; so they cannot be used longer, but it is known from the life of welds in fire boxes that the weld will last as long as the sheet; there are about two thousand locomotives running in the United States today with some part of the boiler welded, most of them with the flues welded in. Broken mud rings may easily be welded in place by cutting out a piece of the sheet at the break, welding the ring, and then welding the piece of plate back again.

Welding Machine Parts. The use of the electric arc for welding machine parts, new and broken, Figs. 83 and 84, is another field that offers great savings because of the delay incident to getting new parts as well as their cost, in cases of breakage, Fig. 85, and the great expense of making satisfactory mechanical joints in new work. Radical changes in design and details of construction are made possible by the use of this system in machine building and the fact that the parts can be so joined as to be literally one piece opens up great possibilities. For work on cast iron the graphite electrode is used and a cast-iron melt bar fused into place with the article in a horizontal position. Cast-steel parts requiring a moderate amount of welding may be done with the metallic electrode but large welds can usually be done to better advantage with the graphite electrode, using a wrought-steel melt bar or pieces of steel plate scrap to fill in with. Cast iron or steel can be welded soft enough to machine readily, by proper treatment, and the quality of the welded section can be made equal to the rest of the article. The effect of the electric arc on the composition of the metal is clearly indicated by Table III.

TABLE IV

Strength of Butt-Welded Joints

Plate Thickness Inches	Elastic Limit Lbs. Per Sq. In.	Tensile Strength Lbs. Per Sq. In.	Elongation % in 8 In.	Per Cent Efficiency
$\frac{1}{4}$	40930	54650	04.5	97.6
$\frac{3}{8}$	44930	53020	05.75	94.7
$\frac{1}{2}$	40160	51280	40.75	91.6

From Table III, it will be seen that it is necessary to use filling material of the proper composition if the weld is to be

Fig. 86. Test Plates Showing Strength of Electric Welds
Courtesy of C & C Electric and Manufacturing Company

the same in composition as the original article. By merely using electrodes and melt bars with an excess of such elements as silicon, carbon, etc., this can be controlled to a very small variation from the desired amount. Unless the operator burns his metal by using too much current or applying it too long, there will be no appreciable

TABLE V

Relative Strength of Joints

Samples and Preparation	Breaking Strain Pounds	Length After Breaking Inches	Per Cent Efficiency
Original piece of plate	58,600	8.80	97.66
Lap joint, arc welded	54,800	8.94	91.33
Lap joint, riveted and welded	54,200	9.22	90.33
Butt joint, arc welded	47,800	8.28	79.66
Butt joint, acetylene welded	36,800	8.23	61.33
Lap Joint, riveted only	35,000	....	58.33

difference in color between the weld and the rest of the piece; so finished surfaces may be welded in many cases.

Strength of Weld. *Butt- WeldedJoints.* The strength of the weld can be made the equal of the article welded by reinforcing, or it can be made very nearly equal by using filling material of high strength and welding flush with the surface of the piece, Fig. 86, this being especially true of steel plates. Some tests made by the author on steel plates of various thicknesses (with a nominal strength of 56,000 lbs. per square inch) showed the results given in Table IV.

The elongation in the filling material was less than in the original material, of course, owing to its being really a steel casting, but its ductility can be improved by hammering after welding and this is frequently done when welding heavy sections.

Comparative Test. In order to test the relative strengths of riveted, electric-arc-welded, and acetylene-welded joints, a set of steel samples were made up and tested as follows, each piece being $\frac{3}{8}$ inches by $2\frac{13}{32}$ inches in cross section and 8 inches long in the straight portion, Table V.

The steel plate used had a nominal strength of 60,000 pounds per square inch but was actually not up to standard, although it showed clearly the relative advantages of the various methods of making joints. Some tests recently made in England are shown in Table VI. Strength of welded piece was 88.43 per cent of original plate.

TABLE VI

Relative Strength of Original and Welded Plate

	Size of Sample Inches	Breaking Strain Pounds	Per Cent Elongation in 4 Inches	Per Cent Reduction of Area
Welded piece	.125×1.48	42,702	10.93	5.23
Original piece	.125×1.48	48,290	32.03	29.63

TABLE VII

Time and Cost of Welding

Article Welded	Time	Cost
Steel casting, shrinkage crack 6" long by 1" deep	8 min.	$00.04
Steel casting, riser 4" by 4" cut off	4 min.	.05
Forged steel locomotive frame, broken in 2 places	20 hrs.	18.28
12" crack in back sheet of locomotive boiler	9 hrs.	5.47
Building up worn driving wheel instead of turning down	2 hrs.	.72
Welding 67 cracks in old fire box (saving over $1000)	2 wks.	52.60
Cast-steel tender frame, broken in 3 places	27 hrs.	19.00
Steel shaft, 2" diameter, broken, welded ready to finish	1 hr.	.60
Broken railway type motor case, cast steel, welded	3 hrs.	1.95
Enlarged holes in brake levers, steel bars	4 min.	.05
Building up 2" armature shafts, worn in journals	3 hrs.	1.80
Air brake piston rods, broken, welded ready to finish	30 min.	.35
Leaking axle boxes, cracks, welded in position	15 min.	.15

Cost of Arc Welding. The cost of arc welding will vary according to the nature of the work, the skill of the operator, and the cost of labor and current, but it is much less than for similar work done by any other process. It ranges from about three-fourths down to one-tenth that of the cost of acetylene welding, for various jobs, and the time required is much less. With the electric arc it is not necessary to keep a large portion of the work heated in order to prevent the chilling of the filling material, because the work forms the hottest (positive) terminal of the arc and a sufficient volume of heat is generated at the point which is being worked upon to insure perfect fusion.

Cost Data in Steam Railroad Shops. The figures in Table VII show the cost of several actual jobs done with arc welders, the labor being paid at the rate of 30 cents per hour and the current costing 2 cents per kilowatt hour, with the filling material figured at 8 cents per pound.

Comparison with Old Methods. The figures in Table VII will give a fair idea of the class of work and the costs of welding in steam railroad shops and car shops, and those in Table VIII will show the savings effected through the use of arc welding instead of making repairs by the old methods, of whatever kind.

Street Railway Repairs. Repairs to electric railway apparatus are also important in order to keep the rolling stock in useful service. The figures in Table IX, which give average costs for performing typical repair jobs in street car shops, are based upon the

TABLE VIII

Relative Costs of Repairs

Article Welded	Welding	Old Cost	Saving
Engine main frames, both broken	$11.80	$56.20	$44.40
Driving wheel built up $\frac{3}{16}''$ on tread	.72	8.00	7.28
General repairs on fire box side sheets	66.51	342.62	276.11
Filling worn knuckle joint bushing hole	.75	7.50	6.75
Welding 7 cracks in locomotive cylinder	22.35	367.15	344.50
Broken mud ring on locomotive boiler	32.07	118.06	85.99

relation between the cost of electric welding as opposed to replacement because that is usually the alternative.

One of the electric railway companies claimed that they repaired about 1600 articles a year which, if replaced by new pieces, would cost them nearly $15,000.00, and had also the benefit of the large amount of time saved by doing the work quickly and keeping their rolling stock in service a larger portion of the time. The use of electric-arc welding apparatus is not confined to the railway field, but equally interesting figures could be given as applying to work done in foundries, machine shops, boiler and tank shops, garages, and other places. These few will serve, however, to show the possible savings through using the arc for repair work in general.

In conclusion, it should be remembered that in order to weld with the arc it will require some practice in starting the arc, especially with the metallic electrode. The "trick" consists in touching the work and getting away as quickly as possible to the required distance, and yet not going so far as to rupture the arc. If the electrode is of metal, it will heat and stick to the work unless withdrawn quickly,

TABLE IX

Street Railway Repairs

Article Welded	Welding	New Part	Saving
Armature shaft, repaired in place	$ 1.70	$ 4.72	$ 3.02
Armature shaft, large, repaired in place	1.97	15.13	13.16
Railway motor axle cap, large	.22	3.51	3.29
Railway motor armature bearing cap	.27	6.07	5.80
Railway motor gear case, top half	.48	7.30	6.82
Truck side frame, Brill 27-G	.72	44.40	43.68
Truck side frame, Peckham 14-B	.90	46.98	46.08
Brake head, building up worn socket	.06	1.15	1.09
Motor frame, G. E. 90, railway type motor	2.88	16.80	13.92

but it can easily be broken loose by a twisting motion of the hand. Care should also be exercised to see that the eyes and face are fully protected from the glare and heat of the arc, as it is hard on the eyes and affects the skin like bad sunburn. On the other hand, some men have done arc welding for years with no injury.

ELECTRIC-ARC CUTTING

Advantages of the Method. Cutting with the electric arc can be done very rapidly and economically and is done a great deal in foundries, scrap yards, Fig. 87, and other places. The slot cut is not so narrow as that cut by a gas flame, which is discussed later, but the metal is good after fusing out and may be used again. This

Fig. 87. Cutting Scrap with a Carbon Electrode
Courtesy of C & C Electric and Manufacturing Company

is not always the case with metals cut by gas processes because there is a chemical action between the gases and the metals, whereas the arc is composed of the vapors of the metals worked upon and, aside from a slight oxidation when cutting iron or steel, there is no injurious change in the metals cut. Some of the more volatile elements may be reduced by the high temperature but the mass being cut will remain unchanged.

Current Requirements. Cutting is done with the graphite electrode and requires from 100 amperes on sheet metal up to several hundred on heavy castings and forgings. The maximum cur-

rent which it is practical or necessary to use should never exceed 1000 amperes and the usual cutting operations take from 400 to 600 amperes. Direct current at 70 volts is used, the same as for welding, and almost any source of supply will give satisfactory results if proper means are provided for controlling the current. However, apparatus which has been specially developed for the service is much better and more reliable than makeshift devices and, as experience shows that the cost of cutting is just as important as the cost of welding, dead resistances should not be used.

Rate of Cutting. The rate of cutting has been found to be very close to one square inch of cross section per minute for each 100 amperes used in the arc. This rate will be increased slightly for sheet-metal work but applies very closely for heavy sections. On the basis given, a section 4 inch by 6 inch (24 square inches) can be cut in 4 minutes with 600 amperes, and experience shows this to be true. A steel plate 1 inch thick and 1 foot wide (12 square inches) can be cut in 2 minutes with 400 to 450 amperes; copper, aluminum, and other metals can be cut at about the same rates as steel sheet. When cutting it is necessary to make the slot wide enough to allow the arc to reach to the bottom of the cut instead of jumping to the sides and the piece should be placed so that the molten metal can run out of the slot. Work should begin at the top of the piece.

ELECTRIC BUTT AND SPOT WELDING

Characteristics and Development of the Process. The use of the electric current to heat metals to the welding point, by passing the current through the joint until the metal becomes plastic and then applying sufficient pressure to cause the pieces to adhere, was first proposed by Elihu Thomson in 1877; and the present day process of "resistance welding", in its various forms, is the result of his work. The process is based upon the phenomenon that a poor conductor of electric current will heat if current is forced through it, or that a good conductor will also heat if enough current is passed through it, and that the heating effect will be greater if alternating current is used than if direct current is used. Since an imperfect joint between two pieces of metal is a poor conductor and offers resistance to the passage of current, it will naturally heat and finally cause the metal to soften sufficiently to weld. In practice the opera-

tion is very rapid because comparatively large amounts of current are used and heavy pressures are applied.

Fig. 88. Welded Bars Showing Upset
Courtesy of Toledo Electric Welder Company

Originally this process was used to weld bars and strips together, end to end, Fig. 88, performing the operation known as "butt weld-

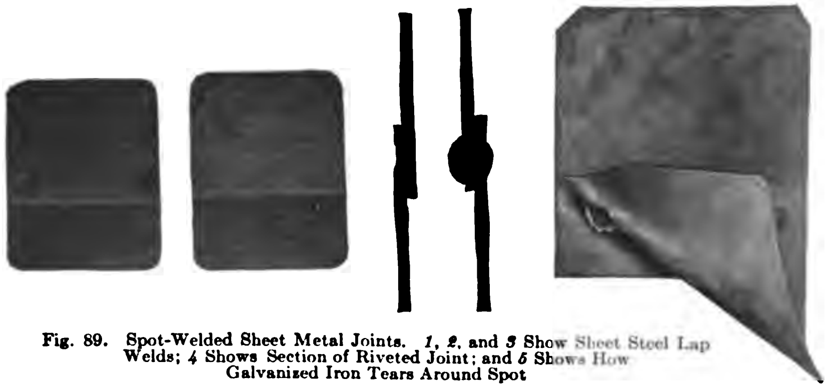


Fig. 89. Spot-Welded Sheet Metal Joints. *1*, *2*, and *3* Show Sheet Steel Lap Welds; *4* Shows Section of Riveted Joint; and *5* Shows How Galvanized Iron Tears Around Spot

ing", and this is today one of the principal uses of the system. Later a modification of the system was made in order that pieces of sheet

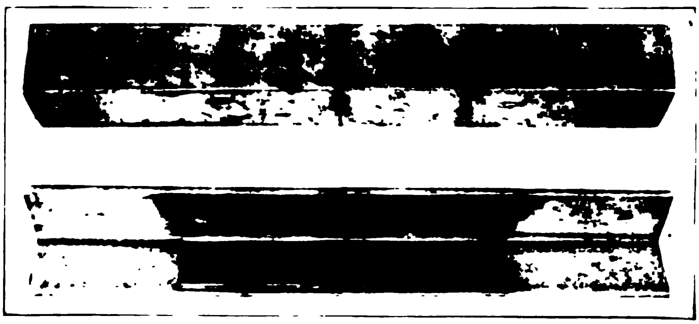


Fig. 90. Single Strap Butt Joint, Spot Welded
Courtesy of Toledo Electric Welder Company

steel could be welded; this resulted in the development of the operation known as "spot welding", by means of which lapped joints can

TABLE X

Metals, Alloys, and Combinations of Different Metals Actually Welded by the Thomson Process

METALS					
Wrought Iron	Wrought Copper	Tin	Cobalt	Aluminum	Gold (pure)
Cast Iron	Lead	Zinc	Nickel	Silver	Manganese
		Antimony	Bismuth	Platinum	

ALLOYS					
Various Tool Steel	Mushet Steel	Wrought Brass	Fuse Metal	Aluminum and Iron	Silicon Bronze
Various Mild Steel	Stub Steel	Gun Metal	Type Metal	Aluminum Brass	Coin Silver
Cast Steel	Crescent Steel	Brass Composition	Solder	Aluminum Bronze	Gold Alloy
Chrome Steel	Bessemer Steel	Nickel Steel	German Silver	Phosphor Bronze	

COMBINATIONS					
Copper to Brass	Brass to Wrought Iron	Brass to Tin	Wrought Iron to Tool Steel	Wrought Iron to Mushet St.	Wrought Iron to Nickel
Copper to German Silver	Tin to Zinc	Brass to Mild Steel	Gold to German Silver	Wrought Iron to Stub Steel	Tin to Lead
Copper to Gold	Tin to Brass	Wrought Iron to Cast Steel	Gold to Silver	Wrought Iron to Crescent St.	Mild Steel to Tool Steel
Copper to Silver	Brass to German Silver	Wrought Iron to Mild Steel	Gold to Platinum	Wrought Iron to Cast Brass	Nickel Steel to Machine Steel
	Brass to Platinum	Steel to Platinum	Silver to Platinum	Wrought Iron to German Silver	

be made, Fig. 89, particularly for thin material. Heavy plates cannot be spot welded so readily as thin ones but they are frequently welded edge to edge, forming a butt weld, or a combination butt and

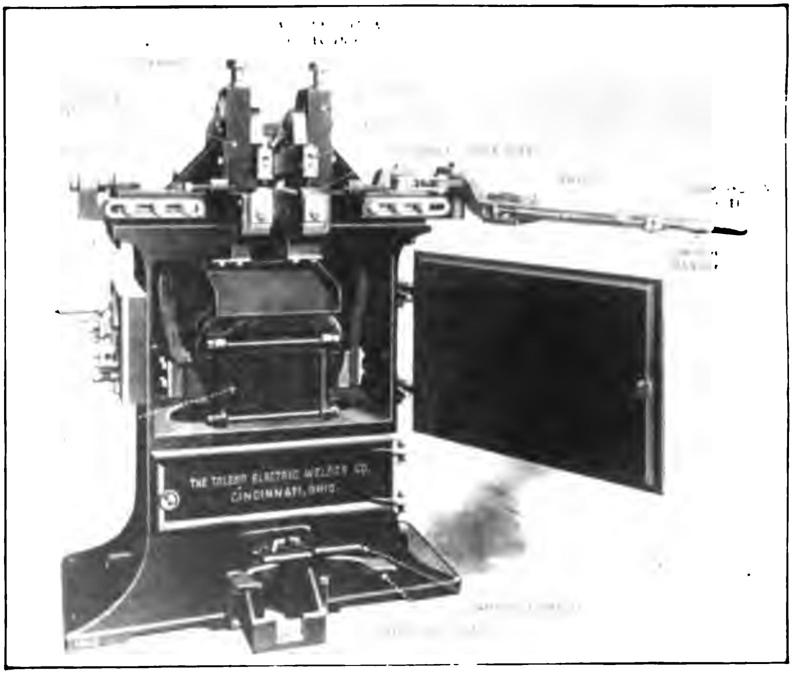


Fig. 91. Double Treadle Butt Welder
Courtesy of Toledo Electric Welder Company

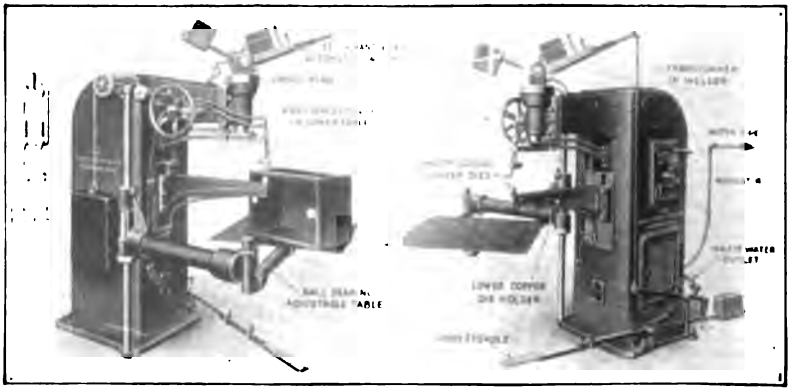


Fig. 92. Principal Parts of Spot Welder
Courtesy of Toledo Electric Welder Company

lap weld, as in Fig. 90. Special machines have been developed by the various manufacturers for numerous operations and for a wide range of articles, a few of which are shown in subsequent illustrations, and the work done with them is of the highest class. Practically every kind of metal can be welded by this process and many different kinds may be joined to each other, as shown in Table X. The great advantage of this process lies in the amount of work which can be done in a short time, but it is limited almost exclusively to the production of new articles instead of being also good for repair work like the arc system.

From a study of Table X it will be seen that practically all of the commercial combinations of metals can be made with butt or spot welding apparatus and, it may be added, there is no other system in use today that will do welding on as wide a range of metals, alloys, or combinations. This system operates on a very low voltage—about 3 volts—and the important factor, as with arc welding, is the amount of current.

Equipment Required. Butt or spot welding requires practically a separate machine for each class of work to be done, these machines consisting of a main frame, Figs. 91 and 92, containing a transformer and some means for clamping the article to be welded, together with a device for applying the pressure required to force the parts together when heated. Unless the machine is designed for one special sort of articles, it is necessary to have a reactive coil to adjust the current to suit the work and a switch to control this coil. As with any other electrical device, a main switch for connecting the welder to the power circuit is necessary, of course, and the larger sizes of machines are water cooled.

The illustrations scattered through the text of this section show the more important types of machines, and the pipes for carrying the cooling water to the copper contacts are clearly shown on most of them. These machines are built for welding pieces with cross sections as small as fine wires, Fig. 93, and as large as 7 or 8 square inches in section and may require as much as 200 horsepower for large work. Butt- or spot-welding machines can be operated from any single-phase power circuit supplying current at a constant voltage by providing the proper transformer, but direct current cannot be used.

Butt welders are comparatively low machines, Fig. 94, and have the clamps for the work on top, generally in the form of jaws with a lever for operating each pair, Fig. 95, and another lever or a

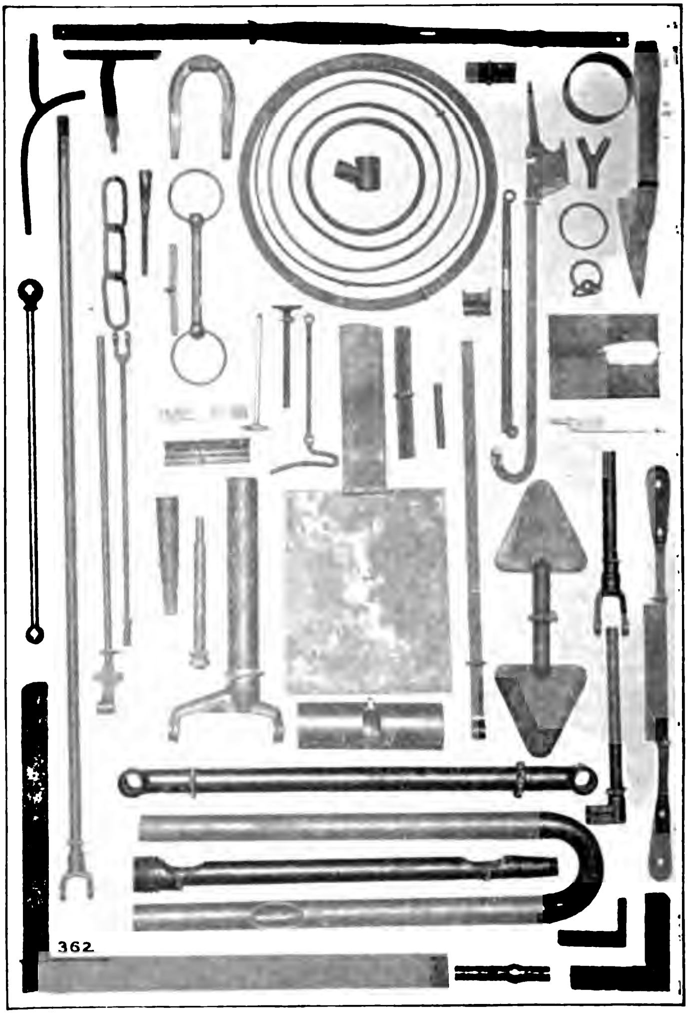


Fig. 93. Samples of Butt Welding
Courtesy of Toledo Electric Welder Company

hydraulic cylinder to bring the pieces together and to apply the required pressure when properly heated. The current is carried into the pieces through the jaws and is usually turned on auto-

Fig. 94. Toledo Small Butt Welder

Fig. 95. Butt Welder Clamps for Pipes
Courtesy of Thomson Electric Welding Company

Fig. 96. Foot-Operated Butt Welder
Courtesy of Geuder, Paeschke, and Frey Company

matically after the parts are clamped into position. Foot levers are also provided on some forms of machines, Fig. 96, for clamping in order to leave the workman's hands free to handle the work. Spot welders, Figs. 97 and 98, are usually higher but smaller and

Fig. 97. Foot-Operated Spot Welder for Sheet Metal
Courtesy of Winfield Electric Welding Machine Company

have a pair of arms, Fig. 99, extending to one side for carrying the two welding tips or contacts; the pieces are laid together and placed on the lower contact and the upper one is forced down against it. The current is automatically switched on, when the contacts close, and the pressure is applied by a hand or a foot lever. Special machines are also made for rail welding, etc. (See Figs. 104 and 107.)

Source of Power. *A. C. City Circuits with Transformer.* The source of power for butt and spot welders should have the same general characteristics as for arc welding; that is, they should deliver the current at constant voltage regardless of load. In most places current can be purchased from a public service corporation and a

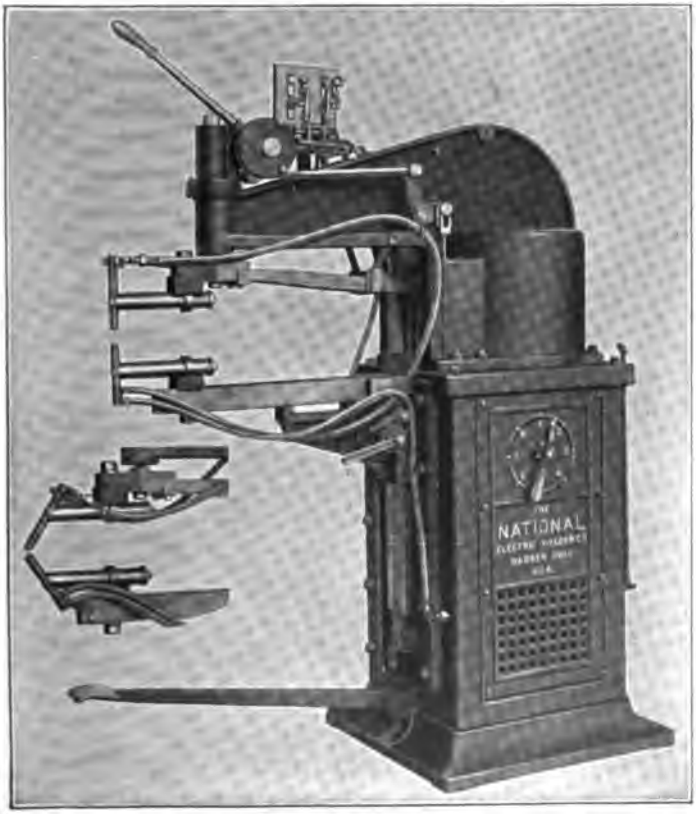


Fig. 98. 24-Inch Drop Arm Spot Welder Showing Different Positions of Universal Points
Courtesy of National Electric Welder Company

transformer, to give current at the desired voltage, will be furnished to power users. City distribution circuits are usually operated at 2200 volts in order to reduce the amount of copper required for the lines and, since alternating current is required for butt and spot welding, it is easy to get current at proper voltage by using a

transformer. Most welders are provided with their own transformers wound to operate on a 220-volt circuit, although they can be made for use on any voltage up to 550 if necessary. Consequently, the line transformer should have a 220-volt secondary winding. The welding transformer will step the voltage down to the proper amount for welding and at the same time increase the current to the required amount. When it is necessary for the user of a welder to furnish his own power, it is best to use a motor-generator set, as such a machine will give better regulation than a rotary converter or a synchronous transformer. Engine-driven alternating-current generators may be used, if adequate means are provided to maintain constant speed under all conditions of load, and this is important for spot welders especially, because of the rapid and wide fluctuations of load in service.

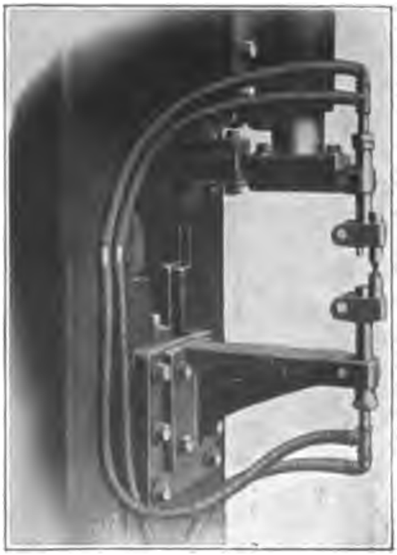


Fig. 99. Details of Spot Welder
Courtesy of Toledo Electric Welder Company

Transformer Requirements. The transformer does its work through magnetic action and entirely without moving parts. It consists of a laminated iron core, or body, with two sets of copper coils or windings so arranged that the alternating current in the line, or primary side, coils magnetises the iron core and sets up a magnetic field which causes current to flow in the welding, or secondary side, coils. The wires and number of turns in the two sets of coils are so proportioned that the secondary coils produce a high current at low voltage, when the primary coils are energized by a low current at high voltage. For most welding operations the voltage is from 3 to 5 volts, and the power required will vary from about 1 horsepower for small work up to 200 horsepower for large work. The power will vary inversely as the time required to make the weld, rapid work demanding more power than slow work.

PROCESSES OF WELDING BY RESISTANCE METHOD

Classification. The process of welding by the resistance method is the simplest of all methods of joining metals, and is also the quickest and cheapest method for work which may be easily handled. While it is true that it is limited almost exclusively to new work and to articles of moderate and small size, it is possible to do work in such quantity and of such variety that this system is used in numerous lines of production. The operation consists mainly in clamping the pieces in the machine, passing the current through the point of contact until it heats, and then squeezing the pieces together until they join. At the proper temperature, the metal will be in a plastic state and the molecules of the two pieces will amalgamate, or mix, so as to unite and form one piece. If the pieces are of different metals, the result will be an alloy of the two metals at the joint. When the nature of the metal is such that it is injured at high temperatures—as, for instance, brass or tool steel—it should be heated quickly and pushed together hard enough to squeeze the burnt metal out of the weld. Experience will soon show the correct heat for the best results on each metal, but the makers of the various welders will be glad to state the proper current, time, and temperature for any sort of work.

Fig. 100. Examples of Spot-Welded Joints
Courtesy of Toledo Electric Welder Company

Butt welding, as its name indicates, is the operation of welding two pieces of metal end to end or side to side, and spot welding is the operation of welding two pieces by lapping them and welding them in spots only, Fig. 100, instead of full width as with butt welding. Numerous modifications of both these processes have been developed for special shapes and sizes of pieces, among which may be mentioned lap welding, tee welding, cross welding, seam

welding, upsetting, jump welding, annealing, and brazing. The two latter applications of resistance-welding machines are not welding in the true sense but are practical applications of the apparatus, which should be understood. Hardening and tempering may also be done through the use of this apparatus and rivet heads, heated ready for shaping, can easily be formed by pressure. Light or small work can be done on large machines, of course, but not very economically, and large work can be done on small machines but it is a dangerous practice on account of the excessive current required and should be discouraged.

Butt Welding. Butt welding is applicable to welding metals of practically the same cross section by bringing them together end to end or edge to edge; all of the energy passing through the joint is effective because it is confined to a limited area of contact. A slight projection or fin will be raised at the joint, Fig. 88, due to the flowing of the soft metal, but this is easily removed.

Spot Welding. Spot welding is the operation of joining sheets by heating and softening the metal in spots only, each about the size of a rivet, and applying pressure while the metal is plastic. The operation causes a slight thinning of the metal at the weld, No. 3, Fig. 89, due to the pressure, but when it is properly done the joint should be as strong as the rest of the sheet.

Lap Welding. Lap welding consists in making a joint by overlapping the edges of the sheets to be welded, heating the joint, and applying pressure by means of rolls which pass along the seam. This makes a continuous seam, instead of merely a series of spots, and gives a tighter and stronger joint than spot welding. It is used to a lesser degree than either of the other methods, but is coming into more general use for special purposes such as welding-in barrel heads, making grease cans, oil tanks, etc. Seam welding is a similar operation.

Butt Seam Welding. Butt seam welding is an operation similar to ordinary butt welding in one respect and like lap welding in another. It is used for making the seam in steel plate articles of moderate thicknesses, such as range boilers; it is done in a machine which brings the edges of the plates together and does the welding by pressure while hot, in the usual manner, Fig. 101. The special feature of the machine lies in the fact that the current is carried into the plates and across the seam by means of rolls each side of

the joint. As the work progresses through the machine, the rolls keep the current always passing across the joint just ahead of where the pressure is applied.

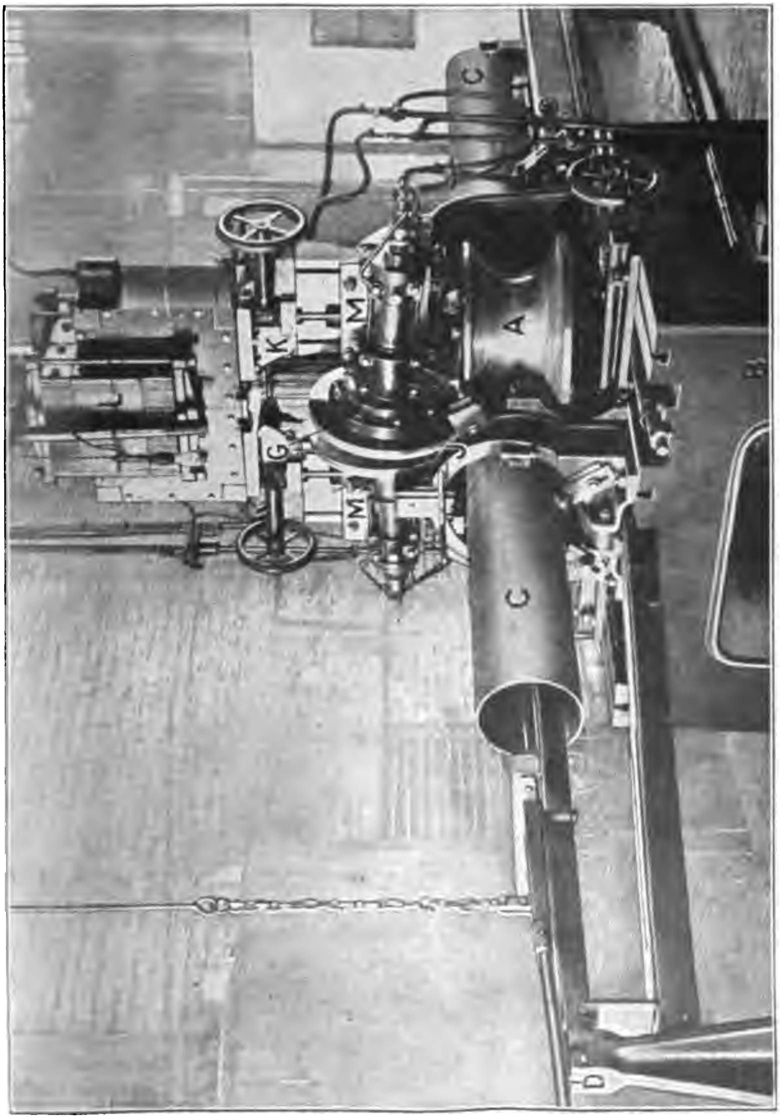


Fig. 101. Electric Welding Machine for Tubes with Tube in Position

Tee Welding. Tee welding is the process of making a weld in the shape of a "T" by welding one piece to the side of another. The

peculiar feature of this process is that the head of the tee must be heated first in order that the shank may not be burned before the parts are both soft enough to weld.

Jump Welding. Jump welding is similar to tee welding and is used on light stock which does not require preheating before welding. This process is also used for pipe work, when forming tees or welding branches into larger pipes, and the hole in the header or main pipe should be made before welding the branch.

Cross Welding. Cross welding is done when forming wires or bars into screens or when making any other article requiring the crossing of strips. The pieces are merely laid together and a welded joint formed at the crossing in either a butt-or a spot-welding machine. The pieces will flatten at the joint, of course.

Upsetting. Upsetting is the operation of forming an enlarged section on a bar for the purpose of increasing its strength or for re-forming it to another shape. The bar is placed between the jaws of a butt welder, the current passed through the space to be upset, and pressure applied when the bar heats. The pressure will squeeze the metal up so that the bar will expand, after which it may be hammered into the desired shape while hot. This process must be distinguished from ordinary butt welding in which the joint swells and shows an "upset". Deliberate "upsetting" is usually carried much further. A "flash weld" is a similar operation and is used on wide stock or on rectangular pieces and when ever the ends of the stock cannot be trimmed square. It consists in squeezing the metal so hard and rapidly while soft that it almost "squirts" apart and forms feathery fins around the joint which must be ground off. It is used when welding brass and copper and an amount equal to the diameter or thickness of the material is taken up in the weld.

Electric Annealing. Electric annealing can be done with either a butt welder or a spot welder and consists in passing the current through the part to be annealed, heating it until soft, and allowing it to cool slowly. Hardened steel plates, springs, dies, tools, chilled rolls, etc., may be treated this way and may then be drilled or cut very readily. When much of this work is to be done, it is better to have a special machine made for the article because it will reduce the cost.

Hardening and Tempering. Hardening and tempering can also be done by heating the pieces in a butt welding machine and, when the desired color is reached, chilling in the usual manner. The advantage in this process lies in the fact that the work is always in sight.

Electric Brazing. Electric brazing can be done quickly by placing the parts in a butt- or seam-welding machine, heating the joint, and then applying the spelter and flux, allowing them to run into the joint. The temperature can be controlled more easily than by any other process and the work is always in sight. It would seem, however, that welding would be preferable to brazing.

Fig. 102. Water-Cooled Die Point
Courtesy of Toledo Electric Welder Company

Electric Riveting. Electric riveting is another recent variation of the spot-welding process and consists in making the holes in the pieces, inserting the rivets, heating them between the tips of a spot welder, and then pressing them to form heads while soft. It is very quickly done and eliminates the rivet heating furnace; for heavy work it is good, but is more expensive than straight spot welding for thin plates.

General Matters of Good Practice. *Freedom from Dirt and Grease.* When doing either butt or spot welding or any of their variations, it is important to see that the surfaces are cleaned thoroughly before starting to weld them because the presence of grease, dirt, or other matter between the surfaces will prevent a perfect joint. The cleaner and better the stock the easier it is to weld, the less current it takes, and the less wear on the dies. Dirt, grease, and scale are insulators, in most cases, and it takes only a small amount, at the low voltage used, to prevent the flow of current; if there is any undue heating in any part of the machine where there,

is a joint in the circuit, it should be carefully examined for dirt and grease and then cleaned. Bolts frequently work loose and, allowing oil to carry dirt under their heads, cause heating. There is no danger of a shock from the welding circuit because of the low voltage but

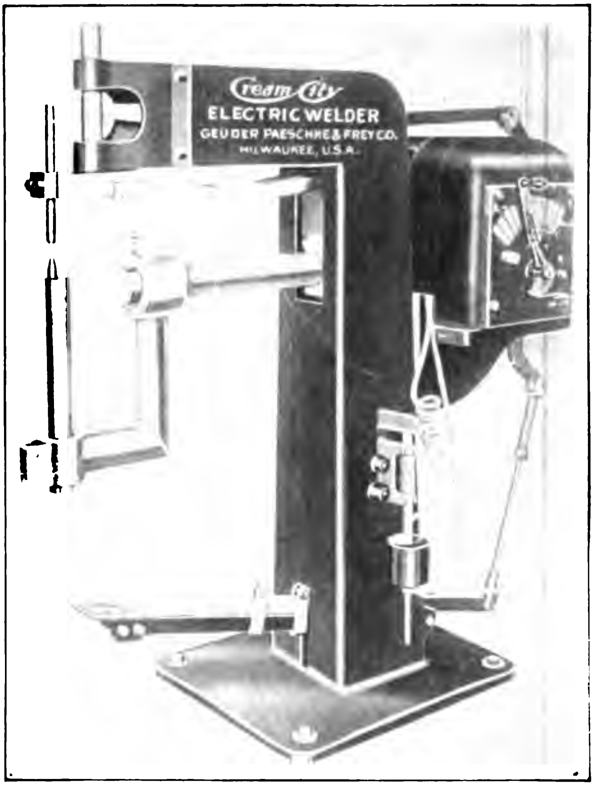


Fig. 103. Spot Welder Showing Simple Construction
Courtesy of Geuder, Paeschke and Frey Company

the line, or primary side of the machine, should be avoided, if possible or handled with proper precaution.

Avoiding Heating of Parts. If the machine has been properly installed, there should be no trouble so long as the cooling water flows through the welding dies, Fig. 102, and everything is kept clean and all connections tight. The only moving parts on most contact welders are the clamps and jaws, Fig. 103, and these are easily watched; the transformer is so simple it should never get out

of order except in cases of accident. The switches should be enclosed to prevent accidental contact and ordinarily are automatic and out of reach.

APPLICATIONS TO MANUFACTURE

General Applications. The applications of welding by this process are too numerous to mention here, but some of the more important ones are in the manufacture of wagon tires, axles, iron wheels, bicycle parts, pedals, brake parts, chain adjusters, tools, shovels, printers rolls, wire and strip hoops, screens, special piping, rail bonding, as shown in Figs. 104 and 105, rings and chains, automobile parts, steering knuckles and rods, step brackets, valve heads and stems, typewriter bars, sheaves and pulleys, umbrella rods, frames, Fig. 106, structural iron work, stovepipe, knives, steel enamelled ware, etc. Practically every kind of metal can be welded and every shape or section that can be put into the machine can be manipulated if the surfaces can be brought together. Special machines for welding the joints in track rails have been devised and Fig. 107 shows the cars and other details of the equipment required.

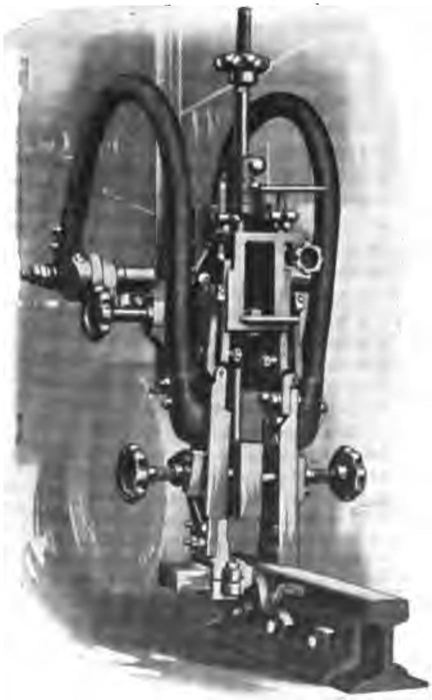


Fig. 104. Spot Welder for Bonding Rails
Courtesy of Electric Railway Improvement Company

Fig. 105. Bonded Rail
Courtesy of Electric Railway Improvement Company

A large spot welder, the details of which are shown in Fig. 108, is used and is made so that the jaws hang vertically down from a crane, with a transformer suspended between them. Pressure is applied through a hydraulic cylinder and plates are welded to each side of the web of the rail. The top of the rails is ground smooth after welding.

When welding hoops, Fig. 96, the strip is bent around and the ends

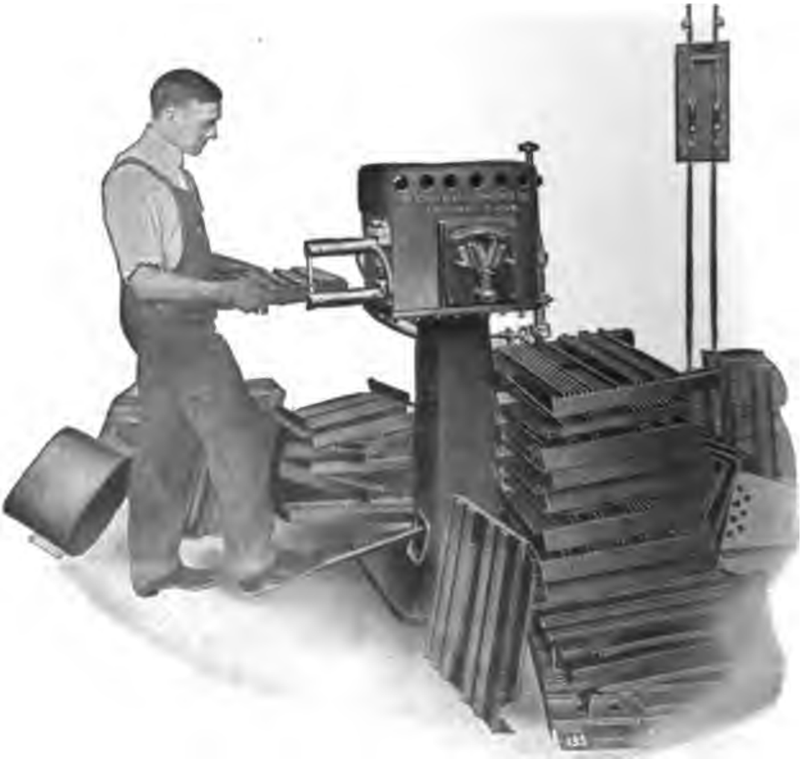


Fig. 106. Spot Welder for Pressed Metal Frames
Courtesy of Toledo Electric Welder Company

brought together and clamped in the jaws of a butt welder. Most of the current will cross the joint, because the jaws are set close and the path across the joint offers the least resistance, although a part of the current will go around the hoop. Chains are welded in the same manner, Fig. 109, and the work is successful in spite of the short length of circuit around the link. Automatic machines are

sometimes used for chain making, wire fencing, screens, and other articles requiring a repetition of numerous simple joints, Fig. 110. Sheet steel and aluminum automobile bodies, mud guards, bonnets, and other parts are spot welded. Coffeepots, Fig. 111, kettles, and similar articles have their spouts and handles spot welded on, and coal pails, wheelbarrow bodies, spiral piping, coal chutes, boxes,

Fig. 107. Electric Rail Welder and Car
Courtesy of Lorain Steel Company, Johnstown, Pennsylvania

cabinets, lockers, steel shelving, and hundreds of other articles offer almost unlimited opportunities for welding by this system. Butt welding is used to almost as great an extent as blacksmith welding and is much cheaper.

Practice with Different Metals. *Iron and Steel.* Iron and steel are used more than any other metals and are, therefore, the metals most commonly welded by all processes; fortunately they are

about the easiest to weld. For butt-welding iron or steel the stock should be clamped in the dies with comparatively little projection and the ends brought together before switching on the current. Considerable pressure is required because it is better to keep the temperature below the melting point. For an upset weld the dies should be about 1 inch apart and for a flash weld they should be about ½ inch apart for ordinary sections.

Cast Iron. Cast iron cannot be welded commercially by this process because of its crystalline structure and the high percentages

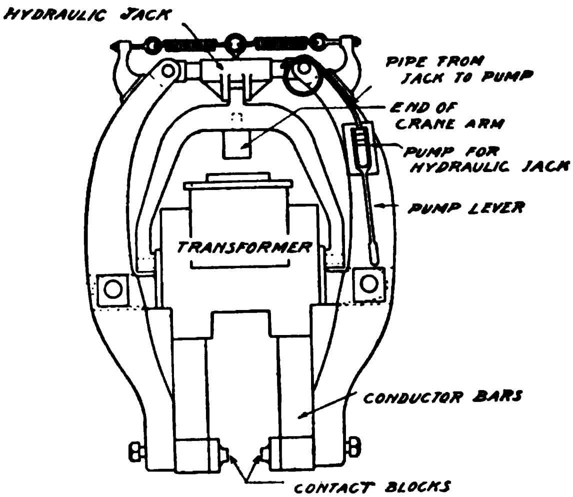


Fig. 108. Diagram of Lorain Rail Welder

of carbon and silicon in its composition. The arc-welding process is the one to use for cast iron, as the metal passes readily from the crystalline to the fluid state when sufficiently heated, which is a disadvantage for butt or spot welding.

High Carbon Steel. High carbon steel can be welded by this process but must be annealed afterwards to relieve the stresses set up by the localized heating. A good joint can always be made with steel of .25 per cent carbon or less, frequently with steel containing up to .75 per cent carbon, but seldom with that containing more than .75 per cent. It requires an experienced operator to get good results with high carbon steel because it is so easily injured. High and low carbon steels can be welded together successfully by

good operators, if the low carbon stock is allowed to project further through its die than the high carbon steel.

Nickel Steel. Nickel steel may be welded readily and the strength is high.

Copper and Brass. Copper and brass may be welded and have the joint strong enough to stand the strain of redrawing through dies but the pressure, when welding, must be less than for iron.

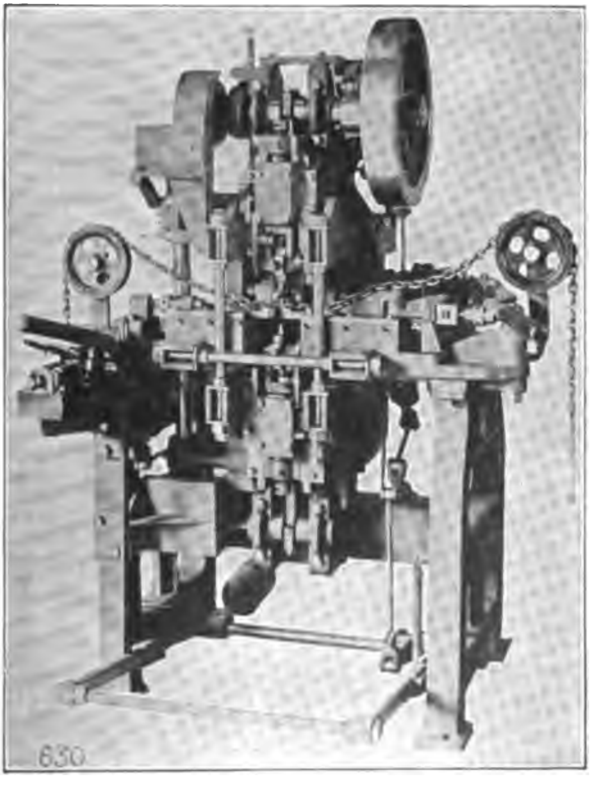


Fig. 109. Semi-Automatic Chain Welder
Courtesy of Thomson Electric Welding Company

The metal is really allowed to fuse, or melt, at the joint and the pressure should be just sufficient to force out the burnt metal. It is because of this that good welds are possible, but the current must be shut off as soon as the ends of the pieces soften, and an automatic switch is provided for this on some machines. The dies should be

set apart 3 or 4 times the thickness of the stock and more current should be used than for iron.

Iron and Copper. Iron and copper can be welded together, if the section of the copper is less than the iron at the point of contact, as the former is a better conductor.

Galvanized Iron. Galvanized iron of No. 22 gage and heavier can be spot-welded but it will burn the zinc off at the welded spot and on both sides of the sheets. For thinner sheets it does not pay to try welding by this method.

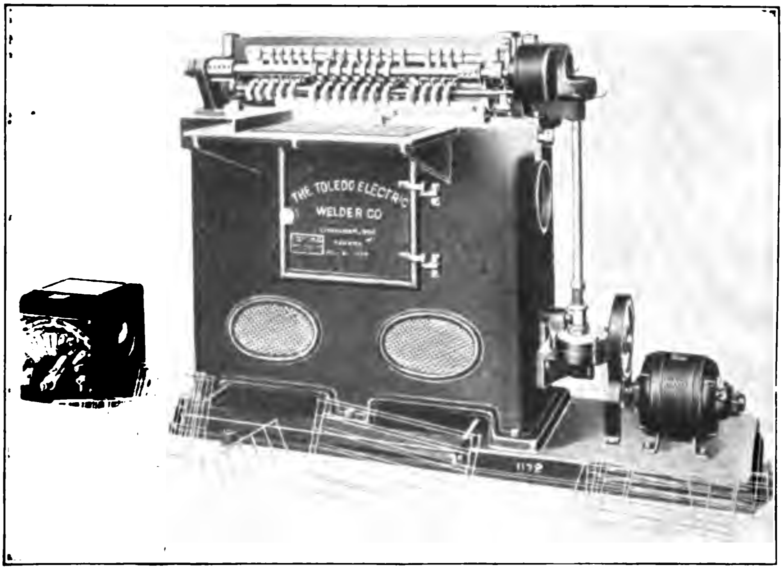


Fig. 110. Electric Welder Capable of Welding Sixteen Wires at One Time
Courtesy of Toledo Electric Welder Company

Sheet Brass. Sheet brass can be welded to brass or to sheet steel after sufficient experimenting to determine the proper heat and pressure.

Sheet Aluminum. Sheet aluminum of some grades can be spot-welded but the surface will be rough and pitted where the die points touch it.

Sheet Copper. Sheet copper is hard to weld because of its low resistance, but it can be done by an experienced operator using sufficient current.

TABLE XI

Power and Time for Butt Welding

IRON AND STEEL				BRASS				COPPER			
Area Sq. In.	Power Kw.	Seconds	H. P.	Area Sq. In.	Power Kw.	Seconds	H. P.	Area Sq. In.	Power Kw.	Seconds	H. P.
.25	6.	20	8.	.125	6.	10	8.	.0625	5.	5	7.
.50	10.	28	13.5	.25	12.	14	15.7	.125	8.5	7	11.5
.75	13.	35	17.5	.375	12.6	17	17.	.1875	12.	9	16.
1.00	18.75	40	25.	.50	15.	20	20.	.250	18.	10	24.0
1.50	29.5	44	39.5	.75	25.	22	33.5	.375	28.5	11	38.
2.00	33.	57	44.0	1.00	29.5	28	39.5	.500	32.	14	43.
2.50	38.	63	50.	1.25	37.	32	50.	.625	37.	16	50.
3.00	43.5	70	58.5	1.50	43.	35	52.7	.75	43.	18	52.
4.00	56.3	80	76.	2.00	53.	40	71.	1.00	55.5	20	75.
5.00	61.7	90	83.	2.50	60.	45	80.	1.25	61.	23	82.
6.00	69.	98	92.5	3.00	66.	49	88.5	1.50	68.	25	91.

Limits as to Thickness of Metal. There is a limit to the thickness of sheets which can be spot-welded and to the sectional area of pieces which can be butt-welded because of the heating of the dies or clamps by the large amounts of current required for heavy work. If enough cooling water is passed through the dies to prevent overheating, it will also carry off some of the heat from the work and a point is soon reached where the area of contact of the dies becomes so great as to be a disadvantage. Theoretically, it is possible to weld any size section with a comparatively small current by leaving it on long enough, but in practice we must take radiation into account, for a point is soon reached where radiation equals the heating effect of the current and, at this point, the temperature remains constant.

Fig. 111. Coffee Pot with Spot-Welded Spout

Power Required. The power required for butt and spot welding is easily determined from the cross section and material of the piece, because considerable experimental data is available. As previously stated, the power required for this kind of welding varies inversely as the time consumed in making the weld. This means that the longer you can take to do the work, the less current you will require; and the quicker you wish to accomplish the work, the more

TABLE XII

Butt Welder Data

Rd. Iron Diameter in inches	Area in Square Inches	Kw. Required	H. P. at Dynamo	Time in Seconds to Make Weld	Cost per 1000 Welds at 1 cent per Kw.
1/4	.05	2	3	3	0.02
3/8	.11	3.5	5	5	.05
1/2	.20	5	7.5	5	.07
5/8	.31	7.5	12	10	.21
3/4	.44	12	17	15	.50
7/8	.60	15	22	18	.75
1	.79	18	25	20	1.00
1 1/8	.99	25	35	25	1.73
1 1/4	1.23	35	50	30	2.90
1 1/2	1.77	50	70	40	5.55
1 3/4	2.41	65	85	45	8.12
2	3.14	75	100	50	10.42

As the rate charged for current varies in different places, we have figured the current at one cent per Kw. hour to give a basis for calculating the cost. Multiply the prices given above by the rate per Kw. hour charged by your local electric light company, and that will give your cost for current for 1000 welds.

current you must use. The total amount of energy in kilowatt hours will be the same in either case, but a larger transformer must be used for rapid work.

Tables XI, XII, and XIII will give a good idea of the power and time required for various thicknesses of metal with butt welding and spot welding, and it will be well to compare the effect of time on the current used.

Table XII is different from Table XI for similar sizes of section because of the difference in the time taken per weld.

Table XII is based only on the use of iron rods, the diameters being given in Column 1. Table XIII is based upon steel, but in the form of sheets. The costs of making the welds as given in Tables XII and XIII are very interesting and should be carefully noted.

Cost of Butt and Spot Welding. The cost of welding by both butt and spot methods can easily be figured from tables XII and XIII by determining the cost of current for the operating conditions under consideration and adding the required amount for labor and overhead charges in the shops. The latter item is very important and will have a noticeable influence on the cost of welding in most shops. The labor for handling the material to and from the

TABLE XIII

Spot Welder Data

Gages of Sheet Steel	Thickness in Fractions of an Inch	Thickness in Decimal Parts of an Inch	Approximate Kw. Capacity	H. P. at Dymano	Time in Seconds to Make a Weld	Cost per 1000 Welds at 1 Cent per Kw.
28	1-64	.015625	5	8	.3	.0045
26	3-160	.01875	6	9	.4	.0065
24	1-40	.025	7	11	.5	.01
22	1-32	.03125	8	13	.6	.0135
20	3-80	.0375	9	14	.7	.0175
18	1-20	.05	10	15	.8	.0225
16	1-16	.0625	12	18	.9	.030
14	5-64	.078125	14	20	1.	.039
12	7-64	.109375	16	23	1.3	.058
10	9-64	.140625	18	25	1.5	.075
9	5-32	.15625	20	30	2.	.112
8	11-64	.17187	23	34	2.5	.16
7	3-16	.1875	25	37	3.	.21
6	13-64	.20312	28	42	4.	.31
5	7-32	.21875	30	45	5.	.42
4	15-64	.23437	33	48	6.	.55
3	1-4	.25	35	53	7.	.68

Based on using fairly clean stock, this table will give an idea of the time and current required in welding different gages of sheet steel.

As the rate charged for current varies in different places, the current has been figured at one cent per kw. hour to give a basis for calculating the cost. Multiply the prices given above by the rate per kw. hour charged by the local electric light company, and that will give the cost for current for 1000 welds in any given locality.

welding machine is just as important as that of the operator himself, and the cost of such labor, together with the interest and depreciation on the purchase price of the welding machine and the cost of installing, are part of the overhead expense. Articles of special shapes will require different amounts of current and experiment alone will show the current required; this factor, with the labor and overhead expenses, will give the cost. It will be self-evident that the better provision one makes for handling the work, the lower will be the cost per unit produced.

Strength of the Weld. The strength of the weld should equal from 75 per cent of the original material on heavy stock up to 95 per cent of it on light stock, when finished to the same diameter or thickness as the piece; this can be made 100 per cent or greater, if a reinforcement can be left on in the form of an upset. The strength of a weld is slightly increased by working after welding, unless there is too much carbon or silicon in the iron. The metal is not damaged

by welding with either the butt- or spot-welding systems, if properly done, because the heat can be controlled so exactly. The oxide which may be present at the joint is usually forced out into the upset and ground off; so a burned weld is a rare thing with this system. In the early days of the Thomson system, there were complaints of weak spongy burnt welds, when made by butt welding, but this was largely due to inexperience and the tendency to heat the metal too much. If an excess of heat is applied, either by using too high a current or leaving it on too long, the metal may be weakened within the heating radius and break about an inch from the joint.

Watertown Arsenal Tests. A number of years ago, a series of tests on electric welding was conducted at the Watertown Arsenal, and the following results were reported in the *Transactions of the American Society of Mechanical Engineers* for 1898:

> Wrought-iron welds averaged from 5 per cent to 10 per cent below that of the plain bars and the fractures were either fibrous or slightly spongy.
>
> Steel welds showed a strength of only from 20 per cent to 50 per cent of the original.
>
> Steel welded to wrought iron showed a strength equal to the iron.
>
> Copper showed a strength of from 90 per cent to 95 per cent of the original stock.
>
> Brass and wrought iron gave very uncertain welds and low strength.

Out of sixty samples welded, twenty-nine broke in the weld; seventeen, within two inches of the weld; eleven, within the range of moderate heat; and two broke near the grips of the testing machine. Some of the steel welds were almost as strong as the bars and some of the iron welds were of slightly greater strength than the bars; so it will be seen that welding by this system compares very favorably with other methods of welding.

Manufacturers of Butt and Spot Welders. There are several firms making butt- and spot-welding apparatus in this country today and it will pay the student to get data from all of them. The principal companies are the Thomson Electric Welding Company, Lynn, Mass.; Geuder, Paeschke & Frey, Milwaukee, Wisconsin; National Electric Welder Company, Warren, Ohio; Toledo Electric

Welder Company, Cincinnati, Ohio; Winfield Electric Welding Machine Company, Warren, Ohio, and the Standard Welding Company, Cleveland, Ohio. All of these makers have certain forms of machines which are adapted to particular lines of products, and they make a specialty of designing machines for any service capable of being performed by this system of welding.

GAS WELDING AND CUTTING

General Features of Method. Hot-flame, or gas, welding and cutting has been a practical process for so long that there is no very clear record as to just when it first came into commercial use, but the development and exploitation of apparatus for the generation and use of gases for welding during the past ten or fifteen years has given an added impetus to the art and it is now used in many ways which were not originally contemplated. The process of gas welding consists merely in joining metals by fusing them together at the point desired through the use of a high temperature gas flame as the source of heat. Various gases and combinations of gases are used and several types of apparatus are now on the market for the purpose. Cutting by the flame is a later development than welding and is both rapid and economical.

Defining Terms. There are two methods of welding in general use, the "Autogenous" and the "Heterogeneous", the names indicating clearly the main difference. The word "autogenous" signifies that the weld is made by the fusion or junction of the articles themselves, without the use of outside filling material to complete the joint. The word "heterogeneous" means a mixture, and signifies that the weld is made by fusing-in some sort of additional filling material, instead of depending entirely upon the metal of the pieces themselves. It is obvious that, if the filling material is of a metal different from the pieces welded, we still have heterogeneous welding; so this name can be correctly applied to brazing or soldering. Custom makes laws, it is said, and custom limits the term "welding" to cases where the same metal is used for a filler as is used in the article welded, and that is the way the term used here. The term "autogenous" has unfortunately come to be applied to all forms of gas welding, and some confusion has resulted because the statement is made that neither flux nor hammering is necessary with

that process. The truth is that fluxes are very beneficial when welding some metals and hammering helps the strength of welds in heavy pieces because it tends to change the structure of the metal from a crystalline to a fibrous nature. Further reference will be made to this later, when discussing methods of welding.

Combinations of Gases with Oxygen. The gases originally used for welding were probably oxygen and hydrogen, and efforts to liquefy them were made about one hundred years ago in order to simplify the means of storing them. It took about fifty years to develop a good process for doing this and resulted in the development of one of the principal present-day methods of producing oxygen. Most of the welding today is done with systems using oxygen in combination with another gas; and the processes take their names from the gases used. The leading processes are known as the oxy-acetylene, oxy-hydrogen (or oxy-hydric), oxy-pintsch gas, blau-gas, water-gas and coal-gas welding processes, the oxy-pintsch-gas process being the latest development. All of these processes depend upon the use of compressed gases, usually stored in strong cylinders and mixed in a burner or torch as used, and may be used for either cutting or welding.

Advantages Claimed. The principal advantages claimed for gas welding are: the simplicity of the process; low first cost of the apparatus; wide range of applicability; light weight of the parts; ease of portability, if necessary; high temperature of the flame; and flexibility of the process for heating purposes. The limitations of the process are: the danger from using an exposed flame; the liability of explosion of the gas tanks and generators; oxidation or carbonization of the weld by the flame; crystallization and cracking of the weld when cooling; and high cost of operation as compared with electric welding. The danger from explosions is being reduced gradually by improved apparatus and the restrictions imposed by the Board of Fire Underwriters.

In manufacturing plants and large repair shops, stationary plants for the generation of acetylene are generally used and the oxygen is purchased from companies making it on a large scale, but some of the larger concerns also make their own oxygen. The same rule applies to the gases used for other processes of welding than the oxy-acetylene. Small portable outfits are also made for moving

about shops which do comparatively little welding, tanks of gas of the proper kind being mounted on substantial trucks. In a few cases small gas generators are mounted on the trucks, but these offer but little advantage over the tanks and are more expensive and harder to handle.

GASES USED FOR WELDING

Gases and their sources form a very important part of the study of the gas-welding processes, because a knowledge of these will often be of great value in determining the best process for particular purposes. This is becoming more necessary because so many concerns are installing their own generating plants in order to get their gases cheaper and more promptly than is otherwise possible. The gases used in hot-flame welding today are acetylene, blau gas, coal gas, hydrogen, oxygen, pintsch gas, and water gas, and various methods are in use for their production and storage.

About one hundred years ago, considerable experimenting was done by the leading physicists to determine the best methods of obtaining the various gases on a commercial scale, and to discover how they might be compressed or even liquefied, with the result that many of the gases in use today for welding were produced on a commercial scale and their value for heating purposes demonstrated, many years ago.

Acetylene (C_2H_2). Acetylene is a colorless gas with a very disagreeable odor, very largely due to the impurities present. It was first obtained by Davy in 1837 when making potassium. Berthelot produced acetylene in 1858 by passing hydrogen through an electric arc, and Wohler produced calcium carbide in 1862 by fusing lime, zinc, and carbon together and then obtained acetylene by adding water to the carbide. Acetylene was first liquefied by Cailletet in 1877 and the use of compressed acetylene was developed by Claude and Hesse. Today, acetylene is obtained almost exclusively from calcium carbide and water, and great care must be exercised to see that pure carbide is used in order to prevent the generation of phosphureted hydrogen along with the acetylene.

Calcium Carbide (CaC_2). Calcium carbide is a dark gray slag formed by fusing lime and coke in the intense heat of an electric furnace; it possesses a great affinity for water. When calcium carbide

is combined with water (H_2O), in the proportion of 2 parts water to 1 part carbide, a chemical reaction takes place which heats the mass and forms acetylene (C_2H_2) and lime ($CaOH_2O$) in the form of ashes. In other words, the carbon combines with the hydrogen to form acetylene and the calcium combines with the oxygen to form lime. One pound of carbide will yield about 4½ cubic feet of acetylene.

Calcium carbide alone is not an explosive and it will not explode even when exposed to the highest heat but, unless it is kept dry, it will absorb moisture and generate acetylene, which is explosive. This is why it is best to store calcium carbide in air-tight tins.

Methods of Storing Acetylene. When mixed with air, acetylene is explosive over a long range of proportions and this makes the gas very troublesome. It is explosive over the limits of 2 per cent gas and 98 per cent air up to 49 per cent gas and 51 per cent air and, when mixed with oxygen, it burns with a tremendous heat. Acetylene dissociates at 780 degrees centigrade into carbon and hydrogen and, when under a pressure of two atmospheres (30 pounds) or more, it is tricky and liable to explode; so it is sometimes stored in specially prepared tanks. Acetylene is readily soluble in liquid acetone, which is cheap, inert, and incombustible; so storage cylinders or tanks are filled partly full of it and then the acetylene gas is compressed into it. Acetone at atmospheric pressure and a temperature of 15 degrees centigrade will dissolve 24 times its own volume of acetylene and, at 12 times atmospheric pressure (180 pounds), it will dissolve about 300 times its volume of acetylene and expand about 50 per cent. The cylinders are partly filled with asbestos fiber to carry the acetone and, to fill the cylinder, it is merely necessary to charge it with compressed acetylene. The various types of acetylene generators will be described later.

Blau Gas. Blau gas is liquefied illuminating gas and is produced by the distillation of mineral oils in red-hot retorts. It contains the same elements as ordinary coal gas but in different proportions; it is free from carbon oxide and is therefore not poisonous. It contains carbon and hydrogen in the proportion of about 5 parts of carbon to 1 part hydrogen and will develop about 20 per cent more heat units than acetylene. Blau gas, named after its inventor, can be compressed and liquefied; when liquefied it occupies but 1/400 part of its gaseous volume and is usually sold under a pressure of

100 atmospheres, in steel cylinders. It is very inert and therefore difficult to explode, the range of explosiveness being from 4 per cent gas and 96 per cent air up to only 8 per cent gas and 92 per cent air. This gas is already used quite extensively abroad, and is beginning to be used more and more in this country.

Coal Gas. Coal gas, or illuminating gas, is produced by the destructive distillation of coal and its discovery dates back to 1727. It is made by heating coal to the point where it decomposes in a closed retort in order that the gas, tar, and other constituents may be saved. Bituminous coal is better for gas making than anthracite because it softens or fuses at a temperature much lower than that required for combustion and this fusion is the commencement of the destructive distillation which forms the solid, liquid, and gaseous compounds from the coal. The operation takes place in specially constructed furnaces and the gas is carried to storage tanks after being washed to remove impurities. One ton of coal will produce about 10,000 cubic feet of gas, 1400 pounds of coke, 12 gallons of tar, and 4 pounds of ammonia, the operation lasting about 4 hours. The gas contains about 5 per cent of hydrocarbon vapors, 13 per cent of carbon oxides, 31 per cent marsh gas, 46 per cent hydrogen, and 5 per cent nitrogen with traces of oxygen, and has a heat value of about 40 per cent that of acetylene. Its use for welding is limited to metals of low melting points and is gradually being superseded by other gases.

Hydrogen. Hydrogen is one of the elements and is the lightest substance known. It is obtained by the decomposition of water into oxygen and hydrogen, both gases being collected and used. Hydrogen is also prepared by passing steam over coke heated to a dull red. If the temperature is not too high, carbon dioxide and hydrogen will be formed ($C+2H_2O=2H_2+CO_2$) but the carbon dioxide may be removed by passing the gas through a vessel of slaked lime. Hydrogen may be liquefied and, when mixed with air or oxygen, is explosive. It is not poisonous but may cause death if inhaled because it will exclude oxygen from the lungs. When hydrogen and oxygen are mixed to form a gas in welding and cutting, they produce a temperature of about 2500 degrees centigrade.

Oxygen. Oxygen is the most important of all of the elements and is used as one of the gases in nearly all welding processes. It

was discovered in 1774 by Priestley and Scheele, both working independently, and in 1789 Lavoisier proved that its presence was necessary for combustion in the air. Oxygen was liquefied in 1877 by Pictet at a pressure of 320 atmospheres.

Methods of Commercial Production. Oxygen is produced commercially by three methods: from the air by liquefaction and fractional distillation; from water by electrolytic action; and from potassium chlorate. The production of *oxygen from air by liquefaction* is by far the greatest source of this gas today for welding purposes, though electrolytic apparatus has recently been developed which is making a strong competitor where power is cheap. The oxygen used for welding must be free from chlorine, although the usual mixture of 5 per cent of nitrogen and from 2 to 3 per cent of hydrogen is no disadvantage. Its production is not a very complicated process, but the apparatus is rather expensive, and only those plants requiring 1000 feet or more per week can afford to make their own gas.

The principal process for producing oxygen from the air is that developed by Linde and consists in liquefying the air and separating the nitrogen and oxygen by fractional distillation, similar to rectifying spirits. The air is first compressed to 1800 pounds per square-inch pressure, and cooled by ice and salt, or ammonia. When the air is compressed, as stated, its temperature rises because of the compression and must be cooled before the compression is continued. The air is, therefore, allowed to expand, thereby cooling itself; then it flows back over the pipes containing the oncoming air, thus cooling the whole body of air. This cool air is again compressed and expanded, growing colder with each expansion, until it is sufficiently near 350 degrees Fahrenheit so that the final expansion to atmospheric pressure liquefies it. Liquid air is 80 per cent nitrogen and 20 per cent oxygen, and commercial oxygen is 95 per cent pure. The balance is nitrogen and is not harmful for welding purposes.

Oxygen is sold in tanks containing 5, 25, 50, or 100 cubic feet, as desired, and the tanks themselves may be either bought or rented. They can be recharged when empty, and each tank is equipped with a reducing valve to regulate the pressure when using. A pressure gage must also be used, when using the oxygen, and leakage must be looked out for because of the high pressure.

The production of oxygen by the *electrolytic decomposition of water* is the method used most in Europe and gives two volumes of hydrogen to one of oxygen. The process consists in passing an electric current at a pressure of 2 or 3 volts through an electrolyte or solution of sodium or of potassium hydroxide. Direct current is used and oxygen rises from the water around the positive terminal plate and hydrogen from around the negative plate, each gas being conducted through separate pipes to compressors for storage. The tank, in which the electrolytic action takes place, is usually of cast iron and is divided into two sections by a partition running part way down. One terminal is placed in each section, and the temperature is maintained at about 165 degrees Fahrenheit because the action requires a lower voltage at this temperature than at any other. From 240 to 325 amperes are used and the gases are about 99 per cent pure. Purity is important because foreign elements may burn into the metal when welding.

The apparatus for making *oxygen from potassium chlorate* is comparatively simple and low priced and is especially suitable for use in out-of-the-way plants doing welding. The process is based on the fact that, when potassium chlorate is heated, it produces a somewhat large percentage of oxygen of 97 to 98 per cent purity. In order to prevent the chlorate from melting and flashing under heat, about 13 parts of manganese dioxide are mixed with each 100 parts of the potassium chlorate, and the gas is given three scrubbings before storing. The mixture is first packed tightly into a retort, heated slowly with a gas flame, and the oxygen is carried through three washer tanks, filled with a solution of sodium hydroxide, and then into a gasometer. From here it is compressed into steel cylinders at 300 pounds per square inch for service. The makers of this apparatus claim that there is but little oxygen lost through leakage because of the low pressures used; that but little oxygen is lost in recharging the retort for the same reason; and that the gas is thoroughly washed in the scrubbers because the bubbles are so large. One pound of chemicals costing about 8 cents will produce about 4½ cubic feet of oxygen at a total cost for everything of about 2½ cents per cubic foot of gas.

Pintsch Gas. Pintsch gas was originally developed for lighting purposes and is used for lighting steam railway cars. It is an oil gas

made from crude petroleum or similar oils and will safely stand a high degree of compression, it being used at various pressures for different purposes. Works for the supply of the gas are now established in nearly all of the large cities in the United States, Canada, and Mexico and gas can be obtained in pressures up to 100 atmospheres (1500 pounds pressure per square inch). It can also be obtained in flasks at 12 atmospheres (180 pounds pressure), but it is used at about 25 pounds pressure for cutting and welding. On account of its high heating value and its stability, or resistance to pre-ignition, it is coming into use for high temperature work in conjunction with oxygen and bids fair to become a serious competitor of acetylene.

Water Gas. Water gas is a mixture of carbon monoxide and hydrogen and is formed by passing steam over or through incandescent coke, thus causing the steam to decompose into oxygen and hydrogen. The oxygen combines with carbon from the coke and forms carbon monoxide, with a little carbon dioxide, and a slight impurity in the form of hydrogen sulphide from the sulphur in the coke. The impurity can be removed with lime or iron oxide, as when making coal gas. Thirty-five pounds of coke are used for each 1000 cubic feet of gas, on an average, and the composition of the water gas is approximately as follows:

Hydrocarbons and vapors	14%
Carbonic oxides	31%
Hydrogen	31%
Oxygen	1%
Methane	20%
Nitrogen	3%
	100%

The apparatus used for generating water gas is comparatively simple and consists mainly of a generator and a superheater, with connections for taking off the gas and for the supply of air and steam. Water gas gives an extremely high temperature when burned and is used a great deal in Europe for heating metals preparatory to welding by hammering as well as for fusing, as in some other processes. Owing to its lack of odor when pure, it is dangerous if it escapes.

OXY-ACETYLENE WELDING

General Features. The oxy-acetylene welding process is the best known of the hot-flame systems and is based on the combustion

of oxygen and acetylene at the tip of a torch as the source of heat. This process has apparently been developed to the highest possible degree and is probably the most efficient of the various hot-flame systems in general use, the flame having an approximate temperature of 3500 degrees centigrade. The practical value of this process was overestimated, when it was first introduced, and there are still many limitations to be overcome but improvements in torches, valves, generators, and storage tanks are being made and should result in improving its status. Owing to the low first cost, there are thousands of oxy-acetylene plants in use for welding and cutting, in spite of the high cost of operating, and reductions in the cost of the gases will eventually bring down the cost of operation to a more reasonable basis.

The principal elements of an oxy-acetylene installation are: the oxygen generating or storing apparatus; acetylene generating or storing apparatus; and the burner or torch with its connections. For large plants it will pay to install oxygen generating plants as well as the acetylene plants, but in other shops the oxygen is usually purchased in steel tanks and the acetylene is generated in small-sized outfits. For moderate sized shops a portable outfit can be used, consisting of an oxygen tank and a small acetylene generator, or an oxygen tank and an acetylene tank on an ordinary hand truck.

Acetylene Generator. The acetylene generator is a comparatively simple device, usually a single steel receptacle for holding the gas, with various attachments for controlling the action of the water on the carbide. There are two general systems of acetylene welding in use, the high pressure system and the low pressure system, both of which have their advocates. As a matter of fact, the so-called high pressure system, used in this country today, is a medium pressure system, the true high pressure system being used principally in France and not yet having been introduced commercially into this country.

Acetylene generators are made in five types, one of which only is used to any great extent for making acetylene for welding use. These are the "dip", the "drop" or "plunge", the "overflow", the "rescission", and the "spray" types, the drop type being the one most used.

Dip Type. The dip generator is so arranged that the calcium carbide is suspended in a sort of basket inside the gas holder and, as the gas is used, the basket is lowered until the carbide comes in contact with the water. More acetylene is then generated and this causes the pressure to raise the holder and basket, thus stopping generation until the gas is used.

Fig. 112. 100-Pound Oxy-Acetylene Welding Outfit
Courtesy of Davis-Bournonville Company

Rescission Type. The rescission generator is similar in principle to the dip type, the only important difference being that the gas pressure forces the water away from the carbide basket instead of lifting it.

Overflow Type. The overflow generator has the carbide in a series of compartments, the water filling the first before overflowing into the second, then into the third, etc., until all of the carbide has been flooded.

Spray Type. The spray generator is one of the oldest types and has a pan of carbide located so that the water may drip into it

from above. The supply of water is cut off when the gas pressure becomes too high and steam is frequently formed by the high temperature of the reaction. These machines are wasteful and dust from the carbide may clog the pipes and burner.

Drop Type. The drop or plunger type of generator is the most economical and satisfactory and has practically superseded all of the others. This type of generator is arranged so that the carbide falls a few lumps at a time into a large vessel of water, the feeding being done by suitable mechanism; the water absorbs the heat so rapidly that the gas is kept cool and the temperature of the entire outfit is much lower than with other types. The gas is washed by bubbling up through the water and the lime remains in the bottom and is frequently removed. This lime makes a good fertilizer. It has been claimed that this type of machine is inefficient because the water will take up gas at the rate of 1 cubic foot per cubic foot of water; but as the water becomes saturated with the lime, it causes the gas to pass out, so that only about three per cent of the gas is actually lost by this action. Theoretically, 1 pound of carbide requires ½ pound of water but, in practice, it takes about 1 gallon to the pound for the best results and should produce 4½ feet of gas.

Fig. 113. Portable Welding or Cutting Oxy-Acetylene Unit
Courtesy of Davis-Bournonville Company

The best known acetylene generator on the market in America today is the Davis generator made by the Davis-Bournonville Company, New York, for use in connection with their welding apparatus, Fig. 112, made under the Bournonville patents. The carbide is fed into the machine through a hopper at the top in the form of lumps, because ground carbide will produce less gas, the

carbide being dropped into the water as required. The feeding mechanism is on top and operates through variations in the gas pressure and through its effect on heavy weights and a moving gas bell. Attached to the tank are also a filter, flash-back chamber, drainage chamber, water filling tube, blow-off valve, and such other devices as are required for the safety and operation of the generator. The pressure of the gas may be varied and can be made to run up to 15 pounds if desired. These machines are made in sizes from 20 pounds carbide capacity up to 300 pounds capacity, a small-sized portable outfit being shown in Fig. 113.

Oxygen Generator. Oxygen generators are much more elaborate devices than acetylene generators and the methods of action of the large types have already been given on pp. 98 and 99. Most of the small plants, whose details may be easily understood, are for making oxygen from chlorate of potassium and consist of a generator, washer, gasometer, and compressor. The generator for

Fig. 114. Medium Welding Torch
Courtesy of Davis-Bournonville Company

the oxygen consists of a metal retort and a gas burner for heating it and the chlorate is mixed with a little manganese dioxide and heated in the retort. The vapor from this is usually carried through three scrubbers, consisting of barrels filled with a solution of sodium hydroxide, thence into a gasometer or tank to be stored until required. From the gasometer the oxygen is carried to a compressor, usually two-stage and there compressed for filling the cylinders at 300 pounds pressure per square inch. Oxygen of high purity can also be generated by wetting sodium peroxide; small outfits of this type have been put on the market under the name of "Oxone".

Torch. The torch is the next item of importance in any good acetylene welding outfit and upon the development of this device

alone depended the success of the oxy-acetylene process to a large extent. It has taken years to bring torches to their present state for the flame is very hot and the gases are highly explosive, yet they must be mixed and controlled accurately. The oxy-acetylene torch was probably invented by Fouche and was a high pressure device; so it was comparatively easy to get a good mixture but, later, it became necessary to develop a torch for low pressure work and it proved to be a difficult matter. It was done, however, and there are now three styles in use: the original high pressure torch, the medium or positive pressure torch, Fig. 114, and the low pressure torch. There is also a special torch for cutting with an extra oxygen feed in addition to the regular flame feed. The gases are regulated by cocks at the handle, and wire gauze is placed in the passages to prevent flashing back in case of too low pressure, somewhat on the principle of the miner's lamp. Torches are made in several sizes and have a series of removable tips to provide for various sized flames. Goggles for the eyes and gloves for the hands of the operator are necessary for his protection.

Automatic Cutting and Welding Machines. A recent development in connection with oxy-acetylene apparatus is the use of special cutting machines and welding machines which work automatically and displace hand welding and cutting. An attendant is necessary, of course, to see that the material is properly placed but the machine does such a high quality of work at such a uniform rate that it can turn out work of a simple nature more quickly and more cheaply than when done by hand. With this machine any irregular pattern may be cut quickly and accurately and it will cut steel 3 inches thick at the rate of 6 inches per minute. The welding machines are especially valuable for work on pipes, barrels, cylinders, cans, and other articles which are all alike, and some very efficient special machines have been built for such service. These automatic machines are not of any value for repair work, to be sure, and do not warrant the cost for any other than repetition or straight work. The torch is carried on an arm which is moved by the mechanism of the machine.

Process of Welding. *Adjusting the Flame.* The process of welding with the acetylene flame is similar to that of using the graphite electrode in electric-arc welding, as the flame is the source of heat

and the filling material must be added as melted, but it has the disadvantage of being an open flame, which presents a certain element of danger. The first thing the operatorhas to do is to learn how to adjust his flame, and this is not easy because there is no rule for the exact proportion of oxygen and acetylene. It is approximately 1 part acetylene to 1.5 partsoxygen for most purposes. If the oxygen is as great as 2.5 against 1 of acetylene, an oxidizing flame will be produced which will probably cut the metal; if there is too much acetylene to be all consumed in the flame, itwill split up and allow carbon to enter the weld and carbonize it. The flame should be so adjusted that the two cones formed in the flame unite into a single small one. In operation, the tip of the white cone in the flame should just touch the metal and the hand should be held steady because, if the tip of the torch should touch the work, it will cause a flash back and necessitate relighting, if nothing worse. The torch should be given a sort of rotary motion around over the surface of the weld, with a slight forward and upward movement, in order to blend the metal and reduce the liability to overheat it.

Care for Expansion During Heating. All welding operations, whether with gas or electricity, should be undertaken only after a careful consideration of the effects of expansion and contraction on both the joint and the piece welded. This is especially important when welding castings, and even more so with the oxy-acetylene system than with the electric-arc system, because of the necessity for heating a comparatively large surface around the weld.

Preheating. Cast-iron pieces and articles of circular or closed shapes, such as wheels, should be preheated before welding and reheated afterwards to relieve any stresses which may be set up in them. Gas furnaces or oil burners make good preheaters as they are much cheaper than using the oxy-acetylene flame for heating preparatory to welding. Heating is necessary for practically all kinds of materials in order to prevent chilling of the flame and consequent loss of efficiency. It is also necessary to choose the proper sized tip to suit the work.

Conditions of Metal and Joint. It is important to have the surfaces clean before starting to weld and, if the parts have been cut with the flame, they must be chipped off in order to remove the oxidized material before being welded. Plates, to be welded should be bev-

eled on the edges, unless they are less than $\frac{1}{8}$ inch thick and filling material of similar composition used for the joint. If the plates are over $\frac{1}{2}$ inch thick, it is advisable to bevel from both sides towards the center in order to balance the shrinkage strains and reduce the amount of filling required. The edges of the bevel should be from 30 to 45 degrees angle and the plates should be spaced slightly apart to insure filling clear through the joint. The opening should flare a little from the end where work begins to the opposite end in order to allow for the parts drawing together as the work progresses. Fluxes are an advantage in acetylene welding in order to absorb or reduce the oxide formed by the flame and to prevent burning out the carbon from high carbon steels, etc. They also protect copper and aluminum from oxidizing and reduce the liability of the zinc burning out of brass.

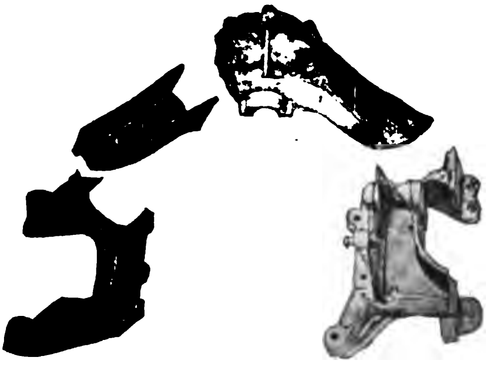


Fig. 115. Broken Aluminum Casting
Courtesy of Davis-Bournonville Company

Effects on Various Metals. Aluminum is very sensitive to oxygen; so an excess of acetylene in the flame is desirable when welding it. The metal does not run readily and must be puddled into place with a rod of iron. It should be hammered to toughen after welding, has a low melting point, and is difficult to weld. Figs. 115 and 116 show a successful piece of work with an aluminum casting.

Fig. 116. Aluminum Casting Welded by Gas Torch
Courtesy of Davis-Bournonville Company

Brass can be welded readily with a moderately large flame, but the cone of the flame should be kept away from the metal. Borax is

Fig. 117. Split Steel Bolster Welded by Gas Torch
Courtesy of Oxweld Acetylene Company

used as a flux for brass and the weld is usually not very strong because the material after being melted is merely cast brass.

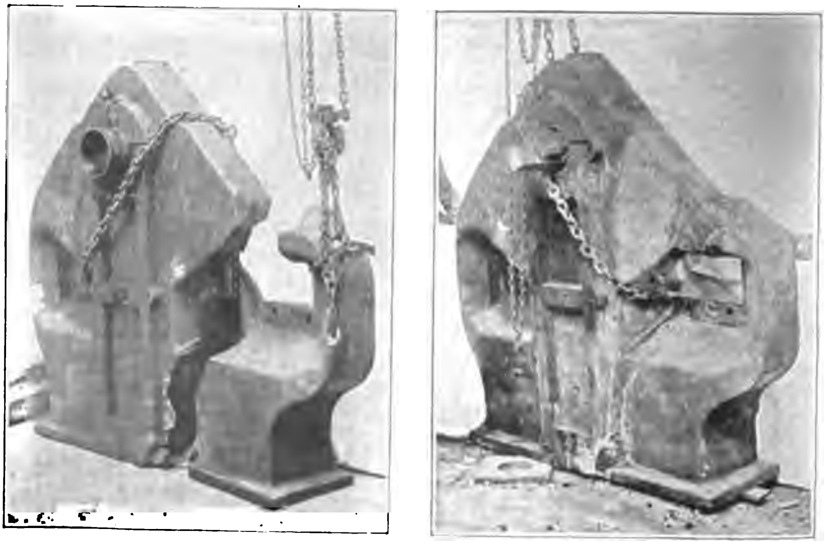


Fig. 118. Immense Shear Casting Broken and Welded by the Gas Torch
Courtesy of Davis-Bournonville Company

Copper should be welded with a low temperature flame and hammered afterwards to restore its toughness. Acetylene attacks

copper, so care must be exercised to see that there is no excess in the flame as it may form acetylide of copper, which is a fulminate and can be exploded by striking with a hammer, or even by high friction.

Cast iron can be welded but is very liable to crack when cooling, so careful preheating is necessary before welding and slow cooling afterwards. High silicon cast-iron melt-bars, which are low in sulphur and phosphorus, are used, and borax forms this flux. Cast iron runs freely and a mold should be made around the spot to be welded to retain it, and the work must be done horizontally.

Wrought iron becomes cast iron when it cools—unless it is very low in silicon—and as it loses its structure it should be hammered to toughen it. It does not readily melt to a fluid but becomes a sort of thin paste and must be worked into place with the melt bar.

Fig. 119. Section of Boiler Flue Ready to Weld
Courtesy of "The American Machinist"

Fig. 120. Welded Boiler Flue
Courtesy of "The American Machinist"

Steel, with a small percentage of carbon, welds more easily than high carbon steel, and the carbon is liable to burn out or so change its structure near the weld as to destroy its essential properties. High carbon steels require careful heat treatment after welding to restore their original properties, and soft steel should be hammered to toughen it. Steel may be welded to iron or copper by proper manipulation but these are uncertain operations and are very seldom necessary.

Alloys of nearly all kinds may be welded with oxy-acetylene apparatus; the principal point to look out for is to be sure that the

composition of the alloy is known before starting. If the flame is adjusted to suit the most sensitive metal and its action watched, there should be no serious trouble.

Applications of Oxy-Acetylene Welding. The applications of oxy-acetylene welding are almost as numerous as are the articles to be welded and apparatus of this type is in use in almost all lines of manufacture and repair. The low cost of the apparatus helped to give this system its present foothold and in many lines it has given entire satisfaction, especially on light work and where convenience is of greater importance than the cost of operation. Castings, forgings, sheets, and tubes of iron, steel, Fig. 118, copper, aluminum, etc., may be welded within the limitations just mentioned, and there is apparently no limit to the size of the piece which may be handled successfully, Fig. 118. Large articles cost more in proportion than small ones because of the greater amount of heat wasted in keeping them hot, but users of the system weld practically everything that comes along. Steel tanks are frequently welded instead of being riveted; car roof seams are welded instead of being soldered; steel furniture is welded in all the joints; cracked cast-iron cylinders are welded; boilers are patched and the flues welded in, Figs. 119 and 120; engine frames, crank cases, and automobile frames are repaired by welding. A good weld is stronger than a riveted joint and the cost is about the same.

Cost of Acetylene Welding. The cost of acetylene welding is very moderate on work of small or medium size but it becomes somewhat high on large work on account of the relative amount of heating to be done while welding. However, the advantages to be gained in quantity of production and even more so in cases of repairs because of the cost of new pieces, makes the system very valuable in many establishments. The cost of welding sheet steel per foot of length of seam is given in Table XIV and it will be interesting to compare this with the cost of doing the same work with the electric-arc system. This table was furnished by the Davis-Bournonville Company.

Repair Work. It is difficult to get accurate figures on the cost of doing miscellaneous repair work because the average repair man does not like to tell, but the following are the charges made in one automobile repair shop and will give an idea of what such work costs because the profits charged are usually 100 per cent of the cost.

TABLE XIV

Approximate Cost of Oxy-Acetylene Welding

Tip Number	Thickness of Metal in Inches	Consumption of Acetylene in Cu. Ft. per Hour	Consumption of Oxygen in Cu. Ft. Per Hour	Proper Pressure in Pounds for Oxygen	Lineal Feet Welded Per Hour	Cost of Labor Per Hour	Total Cost Per Hour	Cost per Lineal Foot
1	$\frac{1}{32}$ to $\frac{1}{16}$	2.8	3.6	8 to 10	50	$0.30	$0.436	$0.0087
2	$\frac{1}{16}$ to $\frac{3}{32}$	4.5	5.7	10 to 12	30	.30	.516	.0172
3	$\frac{3}{32}$ to $\frac{1}{8}$	7.5	9.7	12 to 14	25	.30	.666	.0266
4	$\frac{1}{8}$ to $\frac{1}{4}$	11.7	15.	14 to 18	16	.30	.867	.054
5	$\frac{1}{4}$ to $\frac{5}{16}$	18.	23.	18 to 22	10	.30	1.17	.117
6	$\frac{5}{16}$ to $\frac{7}{16}$	25.	32.	20 to 25	7	.30	1.51	.216
7	$\frac{7}{16}$ to $\frac{1}{2}$	32.5	41.5	22 to 27	5	.30	1.87	.374

NOTE: The acetylene is used at a pressure of about 3 lbs. per sq. in. The cost of oxygen is estimated at 3 cents, and of acetylene at 1 cent per cubic foot. Labor is estimated at 30 cents per hour.

Welding axles, from	$2.00 to $5.00
Cracked cylinder water jackets	8.00 to 12.00
Broken cylinder lug welded on	2.00 to 4.00
Cylinders cracked inside	12.00 to 20.00
Broken crank case, aluminum	5.00 to 20.00
Main side frames broken, each	15.00 to 25.00

Defects, known as "cold shuts", frequently develop in steel forgings and the average cost of welding these is from 50 cents to $2.00 each. Engine connecting rods have been welded at $3.00 to $12.00 each, depending upon the size. Stern posts of vessels frequently break during storms and these can be welded for $35.00 on small ones up to several hundred dollars for large ones. Blow holes in iron castings cost 25 to 75 cents to fill in.

The following figures on various repair jobs have been compiled by the Oxweld Acetylene Company, Chicago, and cover a wide variety of work:

Welding stern post of lake steamer "Mullen"	$32.00
General repairs on Cahall water tube boiler	29.49
Small cast-iron gas engine frame, sand spot in one side	.40
Broken locomotive side rod, steel forging	5.22
Short crack in locomotive side sheet, 4 inches long	2.50
Cracked locomotive mud ring, nine hours	22.00
Small patch in side sheet of locomotive fire box	10.01
Medium sized patch in side sheet of fire box	17.38
Three short cracks in fire box sheets, 11 inches total	3.46
Small repairs to steel railway motor case	8.82
Welding lugs on small shaper arm, steel casting	4.50
12-inch crack in end of pressed steel car bolster	6.16
Crack in cast-steel truck side frame, "Andrews" truck	.85
Welding small lug to cast-iron cylinder head	5.89
Patch on side of aluminum crank case for automobile engine	1.50
Cutting risers from large steel castings, per sq. in	.014

In conclusion, the student is urged to familiarize himself with the rules laid down by the National Board of Fire Underwriters concerning the installation, care, and operation of oxy-acetylene and other types of hot-flame welding apparatus. The complete rules are too lengthy for reproduction here, but a copy can be obtained from the headquarters of the Board in Chicago and will be interesting reading.

OXY-HYDROGEN WELDING

The use of oxygen and hydrogen as the gases for welding and cutting is older than the oxy-acetylene process and dates back to

before the production of oxygen by either electrolysis or liquefaction of air. Oxygen was probably generated in those days from potassium chlorate and manganese dioxide, or perhaps from potassium and sodium peroxides and water, and the hydrogen from hydrochloric acid and zinc. The oxy-hydrogen process was developed by Newman who used detonating gas (pure oxygen and hydrogen mixed) at a pressure of about 3 atmospheres. This gas is still used to some extent in welding platinum, lead, and precious metals but it is rapidly being superseded by apparatus designed to use the oxygen and hydrogen from separate cylinders.

Equipment. The apparatus required for oxy-hydrogen welding is similar to that in use for oxy-acetylene welding and consists primarily of the two steel cylinders for the oxygen and hydrogen (at pressures of 1500 to 2000 pounds per square inch); a mixer and insulator of the gases, together with a regulator; high pressure reducing valves for each of the gases; armored hose; and the special blowpipe, or torch. When the blowpipe is used, there are two tubes leading to it, one for the oxygen and the other for the hydrogen, and the blowpipe is made with an inner and an outer tube. The oxygen is carried through the inner tube and the hydrogen is carried through the outer tube and lighted first. After the oxygen is turned on, the flame is adjusted to suit the work in hand and the mixing is done in the tip of the blowpipe just before the gases enter the flame. Hydrogen and air can be used with the same sort of blowpipe for light work requiring but moderate heat, such as lead burning, but the process is much slower and more expensive than with the oxy-hydrogen flame.

For commercial welding another type of torch is used and the gases are combined in the mixer and carried to the burner through a single tube. This torch has an enlargement, where the gases enter, which reduces their velocity; from this chamber the gases pass through the smooth tubular body to the nozzle. Th e latter diminishes in size toward the tip and causes the gas to increase in speed up to the proper velocity.

Handling Oxy-Hydrogen Torch. The oxy-hydrogen flame is pale blue, almost colorless in fact, and has a temperature of about 2000 degrees centigrade. When lighting the torch, the hydrogen should be turned on about two-thirds and ignited; the oxygen

should then be turned on enough to give a pale blue conical flame, and then the hydrogen should be turned on full. This will take but a few seconds, and a flame, which will not melt the metal too rapidly, is better than one of such intensity as to burn the work. The end of the cone of oxygen in the flame should never touch the work or that will burn it also. When through welding, the oxygen should be turned off first. Theoretically, two parts of hydrogen should be used for each part of oxygen but experience shows that it is desirable to use about three parts of hydrogen to one of oxygen. Some operators advocate using even more hydrogen, but this is not necessary when the gases are properly mixed before entering the flame.

Process of Oxy-Hydrogen Welding. The process of welding with oxy-hydrogen is similar to other hot-flame processes and the joints must be beveled in the same way to make them accessible for filling. The work should be heated first, in order to prevent chilling of the filling material, and the melt bar fused in to make the joint. In Germany this gas is used to heat plates and then they are welded by hammering, as in blacksmith work, this operation being used to a large extent in making large steel pipes. Iron, steel, copper, lead, zinc, and the other industrial metals can be welded by this process; the cost is similar to that for work done by the oxy-acetylene process, although somewhat higher for most operations. Each metal requires its own special method of treatment and the operator will soon learn the best ways of handling each job, but this process requires a skilled workman and the success or failure of the weld will depend largely on the man who does it.

Time Required for Weld. The time required for welding seams in steel plates will vary from two minutes per foot on $\frac{1}{32}$-inch sheets up to five minutes on $\frac{1}{4}$-inch plates. It is claimed that the oxy-hydrogen flame does not affect the ductility of the metal like the oxy-acetylene flame and, if this is true, it should be good for boiler repairs and other work in which this quality is desirable.

OXY-PINTSCH GAS WELDING

The use of pintsch gas and oxygen for hot-flame welding is the latest addition to the list of possible systems for general use, and was developed by the Safety Car Heating and Lighting Company, New York, primarily for use by steam railroads. It is as general

in its applications, however, as any of the other systems and the fact that every railroad has pintsch gas on its cars and supply stations at frequent intervals should result in a wide application in shops which have no electric-arc welding apparatus. The principal feature of this process seems to be in the use of a special torch, as with the other gas systems, and the apparatus is similar.

Equipment. The apparatus consists of the two steel cylinders for the gases, valves for regulating the pressure, tubes for the gas, and the special torch. The pintsch gas is furnished at a pressure of 100 atmospheres (about 1500 pounds) and the oxygen at 150 pounds. The gas can also be obtained at 180 pounds pressure. The high pressure gas is reduced in two steps when used, the first being from 100 atmospheres to 14 atmospheres and then down to the 25 pounds required at the torch. The torches for this process are made to take the two tubes feeding the two gases and mixing them in a chamber at the back end, and a valve is provided in each inlet. The tip of the torch contains a preheater which operates by internal combustion and produces a high temperature, non-oxidizing flame. This feature of the torch is valuable and adds to the temperature of the flame.

The process of welding with the oxy-pintsch flame is the same as with the oxy-acetylene flame, but the manufacturers claim considerable saving in cost of operation. They give 3.4 cents as the cost of cutting one foot of an 18-inch channel $\frac{11}{32}$ inch thick, and the total cost of the work done on the channel was 86.2 cents against the old cost of $4.66 by drilling and chipping. No figures are available at this time for welding operations, but all sorts of articles can be successfully welded and cut by this process. The preparation of the joints should be the same as for other gases and the metal should be handled in the same way.

BLAU-GAS WELDING

General Advantages. The advantages claimed for the blau-gas process are safeness, cheapness, compressibility of the gas to a liquid, high B. T. U. (1800 per cubic feet), and convenience. On the other hand, the oxy-blau gas flame is not so hot as the oxy-acetylene and must be larger to do the same work. This is sometimes a disadvantage. This system is well established in Europe

but has been adopted in this country only a few years and has not proved a very serious competitor of the other systems. Blau gas is distilled from fuel oil at only 600 degrees centigrade; so the hydrocarbon gases are not broken up and very little tar or methane is formed. During liquefaction for the market, the distillate is first subjected to two compressions which liquefy the low pressure gases and these are drawn off with the cooling water. The heavier gases are then compressed in two more stages and absorb most of the permanent gases when they liquefy.

Equipment Cylinders. The apparatus used for blau-gas welding consists of the regulation gas cylinders containing blau gas at 100 atmospheres pressure, cylinders with compressed oxygen, a gas expansion cylinder, pressure indicating and reducing gages, tubing, and high pressure torches. Owing to the blau gas being composed of gases of different critical pressures it must not be drawn from the top of the cylinders direct; so a tube extends through the liquid gas to the bottom of the cylinders and the heavier liquid is drawn off first. This expands in the expansion cylinder and blowpipe before entering the flame, and the lighter gases are drawn off last. The customary glasses should be provided for the workmen's eyes.

Torch. The welding torch has several sizes of tips and the cutting torch is so arranged that there is a preheating flame around the oxygen inlet. Liquid blau gas is first let into the expansion chamber at about 50 pounds pressure and then into the torch at from 10 to 20 pounds, depending upon the work to be done. The oxygen is led directly to the torch at pressures of 15 to 30 pounds for the various operations. Cutting requires higher pressures than welding.

Process of Blau-Gas Welding. The process of welding with the oxy-blau gas apparatus is similar to the other hot-flame systems excepting that its heating value is less and a larger spread of flame is required to give the required amount of heat units and temperature for the work. The explosive range of blau gas is 4 per cent and ranges from 4 parts gas to 96 parts air up to 8 parts gas and 92 parts air. Up to the present time its principal application has been to cutting, but it has been used for welding practically everything and a large amount of steel piping and tank work has been done with it. It is comparatively safe to use because it is chemically inert, nonpoisonous, and leaves no deposit in the pipes.

Water-Gas Welding. Water-gas welding is done by mixing oxygen with the gas and using it in a manner similar to the other gases. The gas is drawn from the mains and carried to the torch and there mixed with the oxygen for use. Its application is not very general because of [its low heating value, but it is cheap when it can be obtained at all. It can also be obtained compressed into cylinders like the other gases but there is very little to

Fig. 121. Davis-Bournonville Cutting Blowpipe

Fig. 122. Cutting Risers from Large Gear
Courtesy of Oxweld Acetylene Company

recommend it for general use in view of the gradual reductions in cost of acetylene.

Fig. 123. Crosshead Slots Cut Out of Drop Forging
Courtesy of Oxweld Acetylene Company

CUTTING WITH GASES

All of the gases described for welding are also used for cutting and offer some advantages over other methods of cutting for various purposes. The work is done by heating the metal to about 1500 degrees Fahrenheit with a flame composed of oxygen and the gas used, and then directing a blast of oxygen against the heated surface. At that temperature the iron or steel has a great affinity for oxygen; so the metal is oxidized or burned up so rapidly that a clean cut is

Fig. 124. Oxygraph for Cutting Steel According to Pattern with Oxy-Acetylene Flame
Courtesy of Davis-Bournonville Company

made in the piece. The metal is entirely destroyed, of course, but the work is done so quickly and the slot cut is so narrow that it is considered no disadvantage. The metal passes off in the form of an oxide. Pieces of almost any commercial thickness may be cut and blast-furnace tap holes have been cut out to depths of 4 feet of metal.

Equipment for Cutting. The apparatus required for cutting consists merely of a torch, Fig. 121, tubes for the gas and oxygen, and a source of supply of gases. The gases are generally supplied in tubes as for welding, and portable outfits are most convenient for

all-around use. The torches used for cutting differ from those used for welding in that an extra stream of oxygen must be carried to the tip end, and this is generally done by an extra tube along one side of the torch. In some forms the oxygen is then carried through the preheating flame, but the most efficient types are those in which the oxygen is brought into contact with the metal just back of the main flame and so directed as to cause the oxygen to strike

Fig. 125. Cutting up the *Maine* with Gas Blowpipe
Courtesy of Oxweld Acetylene Company

the hot spot. The composition or hardness of the metal have no apparent effect on the speed of cutting and chrome nickel steel armor plates 9 inches thick can be cut at the rate of $2\frac{1}{4}$ minutes per foot of cut, with oxy-hydrogen flames. Figs. 122 and 123 show heavy pieces which have been cut with hot-flame apparatus. Numerous cutting machines have been devised for automatic work, among which are those for holes, rails, cams, irregular curves, and straight lines, Fig. 124, and they are much more rapid and efficient than

hand cutting because of their uniform feed and speed. For work on which they can be used they are a good investment.

Applications of Hot-Flame Cutting. The applications of hot-flame cutting are so numerous that only a few of them need be described in order to give a good general idea of its possibilities. The accompanying examples were done with oxy-acetylene, oxy-hydrogen, and other gases and the work is very similar with all of them. The principal characteristic of the work done is the smoothness of the cut, and the cost compares very favorably with that of cutting

Fig. 126. Cutting up Ruins of Quebec Bridge with Acetylene Blowpipe
Courtesy of Oxweld Acetylene Company

with the electric arc. It is cheaper than the arc on moderate and small work but more expensive on large work. The low first cost of the outfit makes it appeal to small shops and scrap dealers, although it is very valuable for cutting up junk and all sorts of wreckage. The battleship *Maine* was dismantled with an Oxweld acetylene outfit, Fig. 125, and the ruins of the Quebec bridge were also cut away with this apparatus, Fig. 126. Manholes in tanks and boilers, portholes in steel vessels, ruins of burned or wrecked build-

TABLE XV
Cost of Cutting per Foot of Cutting Length

Thickness of iron in inches	1/8 in.	1/4 in.	5/16 in.	3/8 in.	1/2 in.	5/8 in.	3/4 in.	1 in.	1 1/4 in.	1 1/2 in.	2 in.
Cunsumption of oxygen in cubic feet per foot of cutting length	0.45	0.50	0.60	0.90	1.30	1.90	2.50	3.10	4.00	5.60	7.60
Consumption of acetylene in cubic feet per foot of cutting length	0.12	0.13	0.13	0.18	0.19	0.21	0.25	0.30	0.36	0.41	0.47
Length of time in minutes per foot of cutting length	1	1	1	1 1/4	1 1/4	1 1/3	1 1/3	1 1/3	1 1/2	1 1/2	1 3/4
Total cost in cents per foot of cutting length	1.25	1.35	1.5	2.1	2.7	3.7	4.6	5.7	7	9.5	12.75
Thickness of iron in inches	2 1/2 in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	11 in.	12 in.
Consumption of oxygen in cubic feet per foot of cutting length	8.25	11.80	15.30	20.60	26.00	32.00	37.00	44.00	51.00	59.00	68.00
Consumption of acetylene in cubic feet per foot of cutting length	0.60	0.90	1.20	1.40	1.65	1.90	2.10	2.35	2.70	3.10	3.25
Length of time in minutes per foot of cutting length	2	2 1/2	3	3	3 1/2	4	4	5	5	5 1/2	6
Total cost in cents per foot of cutting length	14.5	20	25	34	42	52	59	71	82	95	108

ings, and, in fact, almost anything of metal may be cut by this process rapidly and conveniently. It is not necessary to have the article in any particular position as the work may be done wherever the operator can carry his torch. Work has been done on the top of high towers and stacks and down in deep holes and in steam vessels, inside locomotives, and on the lower side of bridges.

The cost of cutting steel pieces, per foot of length, using the oxy-acetylene flame is given in Table XV by Messer and Company, Philadelphia, and is approximately correct for other systems.

Cost of Hot-Flame Cutting. The cost of cutting will depend upon the cost of the gases, cost of labor, the nature of the work, and the facilities for handling it, but a few typical jobs will give a good idea of the possibilities. The accompanying connecting rod forging for a stationary engine is 6 inches thick and the crosshead slots are each $9\frac{1}{2}$ inches by 7 inches in size and were cut out in 15 minutes each. The total cost of the operations was $6.00, including labor and gas; whereas the usual method of drilling and chipping would have taken 8 hours for each slot and have cost more. In steel and iron foundries this system is used for cutting off risers and gates from the castings and, in boiler shops, for cutting plates of considerable thickness, cutting off rivet heads, cutting holes, etc. The 4×6 foot plate, $\frac{9}{16}$ inch thick, shown in one of the illustrations is a cross brace plate for a locomotive frame and was cut as shown in one hour. The total amount of cutting was 264 lineal inches, which is at the rate of $3\frac{3}{4}$ minutes per running foot. Where articles are to be welded after cutting, it is necessary to remove the oxidized surface from the cut before welding. This can be done with a pneumatic chisel.

THERMIT WELDING

Welding by the thermit process is really "cast welding", because it is accomplished by pouring "thermit steel" around the parts to be joined. The main difference between this and other methods of cast welding lies in the method of producing the molten metal. The name for the process is derived from the Greek word *therme*, meaning "heat", and signifies that it is a heat process of welding or that the metal is produced by heat. The name was originally adopted as a sort of trade-mark but has come to be accepted as the name of the process.

Chemical Reactions in Thermit Welding. The thermit welding process is based upon a long series of experiments carried on for a number of years by various physicists and metallurgists to find some method of reducing metals readily from their oxides and ores. It is the direct result of the work done by Dr. Goldschmidt, of Essen, Germany, in what is now the new field of aluminothermics, and is based on his discovery that if finely divided metallic oxides are mixed in certain proportions with finely divided aluminum they will, if ignited, fuse and produce a temperature of 5400 degrees Fahrenheit in less than 30 seconds without the use of heat or power from the outside. The high affinity of aluminum for oxygen will cause it to draw the oxygen from the metallic oxide, combine with it to form aluminum oxide, raise the temperature of the mass by the violent reaction, and set the metal free. The greater weight of the metal will cause it to flow down through the mass in the container and the aluminum slag will rise to the top.

For ordinary commercial welding purposes in machine shops and foundries, iron oxide is used and the reaction takes place according to the equation.

$$Fe_2O_3+2Al=2Fe+Al_2O_3$$

The liquid steel produced by this process represents one third of the original material by volume and one half of the original mixture by weight, the balance being lost as slag. This method of cast welding was developed about the year 1900 and the peculiar reaction used has also been applied to the production of numerous kinds of alloys and metals free from carbon. Further reference will be made to this.

Analysis of the Composition of Thermit Steel. According to data furnished by the makers of thermit welding apparatus the average analysis of thermit steel is as follows:

Carbon	0.05 to 0.10
Manganese	0.08 to 0.10
Silicon	0.09 to 0.20
Sulphur	0.03 to 0.04
Phosphorus	0.04 to 0.05
Aluminum	0.07 to 0.18
	0.36 to 0.67

The balance of the mixture is iron.

Method of Starting the Reaction. During the experiments leading to the development of thermit welding, the mixture of metallic oxide and aluminum was heated from the outside to start the reaction, but finely divided aluminum will not melt at the temperature of cast iron and it was necessary to heat the mass so high that when action started it resulted in an explosion. So Dr. Goldschmidt used a storm match to ignite a fuse of barium peroxide, (BaO) which in turn ignited the mixture and started the reaction.

Fig. 127. Thermit Crucible Pouring Charge into Mold
Courtesy of Goldschmidt Thermit Company

Equipment for the Process. The apparatus required for thermit welding consists of a crucible, tripod, preheater, yellow wax, and a spade, with which there must also be used perishable materials consisting of thermit, manganese, molding material, and ignition powder. The shell of the crucible is of sheet iron and it is lined with magnesia in order to stand the high temperature and has a magnesia stone thimble at the bottom through which the metal flows. The process of preparing the lining is rather elaborate and must be carefully done or the life of the crucible will be greatly reduced. The

tripod is used to support the crucible above the work, and the preheater is a combination compressed air and gasoline outfit used to heat the article to be welded in order that it may not chill the filling material. The wax is for forming the space to be filled when welding and about which a mold is made. It is melted out of the mold before welding.

Preparing the Mold. The process of preparing the crucible and the mold are the principal features of the entire operation of thermit welding, as the mere act of casting the weld is comparatively simple. The crucible, which is shown in Fig. 127, suspended above the mold, is a sheet-iron shell with a hole below for the metal to pass through. It is to be lined with magnesia, carefully packed

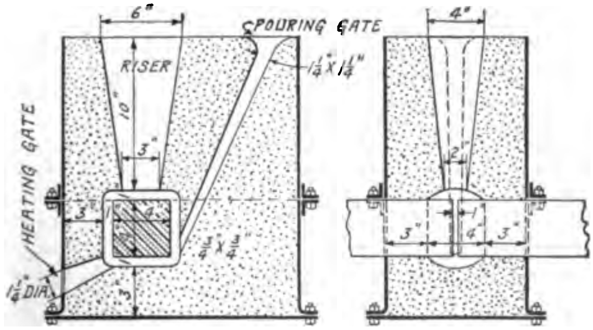


Fig. 128. Section of Typical Thermit Mold Showing Riser, Pouring Gate, and Heating Gate
Courtesy of Goldschmidt Thermit Company

while hot enough to be plastic, and with a magnesia stone thimble at the bottom to form a bushed hole and protect the crucible. The magnesia lining should be put into place slowly and carefully and tamped tightly into place, for its value depends largely upon how hard it is packed. The lining is formed around a matrix to shape the hopper-like center and must be baked at a dull red heat for six hours before it is ready to use. A crucible will withstand about 20 reactions if well made, and must then be relined. The thimble must be placed in the bottom of the crucible so as to be removable.

Construction of Mold. The construction of the mold is really the most important part of the operation, because upon this depends the amount and application of the filling material. The container or flask is usually made of steel plates placed so as to

form a box around the part to be welded, and then filled with the clay, etc., of the mold, the plates being fastened with bolts, tie-rods, clips, or clamps of whatever sort may be available, Fig. 128. The first step in the formation of the mold is to build a collar of the yellow beeswax around the place to be welded, making this of the size and shape desired for the weld. After the collar is formed, the flask is placed around it and filled with a mixture of ground fire

Fig. 129. Preheating Steel Rail Prior to Forming Weld
Courtesy of Goldschmidt Thermit Company

brick, fire clay, and fire sand in equal parts. There must be three channels in every mold, a pouring gate, a riser, and a heating gate. The pouring gate should run from the top of the mold down to the bottom of the wax collar to insure the metal filling the mold and to allow the good steel to reach the weld instead of being crowded out by the slag. The riser should be immediately above the wax collar, if possible, so that the slag and surplus metal can rise freely from the metal of the weld, and the heating gate should run from one side of the mold into the bottom of the collar in order that the wax can

all run out of the mold when melted by the preheating torch. As soon as the mold is completed, the torch is applied and the wax melted out, Fig. 129. The flame is allowed to play into the mold until it is entirely dry and then the heating gate must be plugged with clay to stop it up entirely. Fig. 130 shows a typical thermit weld, with pouring gate and riser still attached.

Thermit Required for a Given Weld. The amount of thermit required to make a given weld will be twice the amount necessary to fill the space formed by the wax collar, because one-half of the weight of the original powder will rise in the form of aluminum slag, as already stated. On the other hand, the cubical area of riser and gate must be twice as great as the collar because the volume of the slag will be two-thirds of the total volume of the casting. It has been determined by experience that the weight of thermit necessary for a given job will be 32 times the weight of the wax required to form the collar for the mold; so the wax should be weighed after melting out of the mold in order to know how much thermit is required for the job. The size and shape of the mold and riser and gate will vary somewhat for different jobs and the relation between weight of wax and mixture will vary accordingly, but the ratio of 32 to 1 is a good average. It is necessary to preheat the article at the joint until it is red-hot before starting to pour the metal, and this is done with the gasoline torch through the heating gate at the bottom of the mold before plugging it.

Fig. 130. Typical Thermit Weld Showing Riser and Pouring Gate Casting Still Attached
Courtesy of Goldschmidt Thermit Company

Addition of Other Materials. When more than 10 pounds of thermit are required for the weld, it is necessary to moderate the

heat of the reaction slightly, and this is done by adding small pieces of clean steel to the powder. These may be punchings, rivets, or any other soft steel pieces but must be free from grease to keep carbon out of the mixture, and from 10 to 15 per cent of the weight of the thermit may be added in this way. About 2 per cent of pure metallic manganese should also be added in order to increase the

Fig. 131. Rolling Mill Housing Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

strength of the weld. If the manganese is not obtainable, 3 per cent of ferromanganese may be added instead, although it increases the violence of the reaction and hardens the metal.

Strength of the Weld. The average tensile strength of the welds made with thermit are 30 tons per square inch of cross section and, if the joint is properly made, it will be hard to see where it is.

Fig. 132. Rails Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

Fig. 133. Broken Stern Post of Boat Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

If a reinforcement can be left around the weld, it will give a higher strength than the original material, but where it is machined off the

Fig. 134. Broken Locomotive Link Ready for the Molds
Courtesy of Goldschmidt Thermit Company

strength will average 80 per cent of that of the piece welded unless it be of unusually high tensile strength. When preparing the joint for welding, it is best to leave an opening for the metal to flow into, and this should be at least $\frac{3}{4}$ inch wide, preferably more.

Applications of Thermit Welding. The applications of thermit

Fig. 135. Welded Locomotive Link with Molds Removed
Courtesy of Goldschmidt Thermit Company

welding are numerous, although the process is better suited to large jobs where the saving in cost of new pieces will justify the cost of the work, Fig. 131. It will be evident also that the process lends itself better to welding large articles than small ones and experience up to the present shows that most thermit welding has been done

on such large articles as engine and machine tool frames, locomotive side frames, and motor cases. Fig. 132 shows a typical thermit weld at a rail joint. This is a modified Clark joint. Another useful application of the method is in welding stern posts and rudder posts of vessels, Fig. 133. The widest application seems to be in steam railroad shops and, while it is true that the electric arc-welding process is rapidly superseding all others for that service, some of the work done is worthy of description. Considerable saving has been made by doing the work without dismantling the engines in order to get at the break. The process is to form the mold about the break, as described, and set the crucible above it ready for pouring. Where it is possible to lay the article on the floor, as when welding crank shafts or a broken link, Figs. 134 and 135, the job is much easier and quicker to perform.

If the break is in the upper part of a locomotive frame, for example, the break should be cut out about an inch and the frame jacked apart another quarter of an inch. The inch space is for filling and the ¼ inch is to allow for shrinkage; so the jacks should be removed as soon as the mold is filled. Breaks in other parts of locomotive frames are treated in the same way. For welding driving-wheel spokes, it is best to heat the adjacent spokes with a torch to expand before welding the broken ones, and then allow them all to cool at once. Rail welding for street railways is another application of thermit and is clearly shown by the cuts herewith, In all cases it is necessary to clean the metal thoroughly around the joint to remove grease and scale, and this is best done with a sand blast so as to insure bright clean metal to fill against. For work of this nature it pays to provide the fullest equipment in order that there may be no failures, because it is a very expensive operation and very hard to do over again.

Use of Thermit in Other Processes. *Foundry Work.* Other uses of thermit are in foundries for improving the quality of the castings and in metallurgical work to produce metals and alloys free from carbon. In foundries it has been found that, by placing a can of thermit in the ladle before pouring, the temperature of the metal will be raised and, by using thermit of the proper composition, the strength of the metal can be increased or its composition varied to suit different jobs. It is also used in steel mills to reduce losses

from "piping" of the ingots. A pipe is a hole formed in the top of the ingot when cooling, due to shrinkage and the presence of slag, and it may extend a considerable distance down into the ingot and reduce its value for rolling. So a can of thermit is thrust down into the top of the ingot at a certain point in the cooling, and this ignites and fuses the steel down and forces the slag out. The mold can then be filled the rest of the way with good steel.

Producing Alloys. The use of thermit, for the production of alloys, etc., has been successful with such metals as titanium, chromium, manganese, vanadium, etc., and alloys of the following compositions have been made.

Ferrotitanium	20–25 % Ti.
Chromium	97–98 % Cr.
Chromium Manganese	30–70 parts
Chromium Copper	10 % Cr.
Chromium Molybdenum	50–50 parts
Manganese	97–98 % Mn.
Manganese Copper	30–70 parts
Manganese Titanium	30–35 % Ti.
Manganese Tin	50–50 parts
Manganese Zinc	20–80 parts
Manganese Boron	30–35 % Bo.
Ferrovanadium	30–35 % Va.
Ferromolybdenum	50–50 parts
Ferroboron	20–25 % Bo.

Ferrotitanium is used as a purifying agent for steel; chromium is used as an alloy with steel to produce crucible steel, etc.; manganese is used to produce very hard steel, bronze alloys, etc.; molybdenum is used in making tool steels; vanadium is used to add to the strength of iron and steel.

TYPICAL AUTOMOBILE STAMPINGS
Courtesy of Toledo Machine and Tool Company, Toledo, Ohio

DIES AND SHEET METAL STAMPING

DIE-MAKING AND USAGE

Study of Details. Having become familiar with the various types of dies for stamping sheet metal, together with a general idea as to the methods employed in making the dies as outlined in a general way in Tool-Making, Part III, it is now essential that the student thoroughly understand the manner in which a die-maker sets about to satisfactorily complete any die. This article deals with die-making proper, entering into each minute detail and description of the various methods and shop kinks practiced by the expert die-maker, together with a description of why a certain piece is made first, and why it is made a certain way; taking up the next piece, and from this to a third, and so on step by step, until the completion of the die.

Grasp of Job Essential. The first step practiced by an expert tool-maker when about to make any tool is to thoroughly understand the drawing from which he is to work; and from a thorough study of the drawing the completed tool in operation can be mentally pictured. The complete understanding of the job at hand is absolutely essential before a cut is made on any piece of steel, for the very nature of the work governs largely which piece should be made first. It is better to spend a whole day, if necessary, in studying the drawing of a complicated tool than it is to have only a vague idea as to the working principle, for more often it will be found that, due to lack of thoroughly understanding the mechanism, several days' time is lost on a spoiled piece of work.

We will take up the actual making of dies as outlined in Tool-Making, Part III.

It is the importance of understanding the working of the machine that emphasizes the necessity of every tool designer and die-maker being an expert mechanic.

BLANKING AND SHEARING TYPES

MAKING SIMPLE PUNCH AND DIE

Size Factor. In Fig. 306 of Tool-Making, Part III, are shown a blanking punch and die for use on heavy stock such as boiler plates. In a simple tool of this character it is immaterial which part is made first. But, should this same type of tool be required for piercing a small hole in heavy stock, the tendency would be to spring the slender punch, and, therefore, in such a case, the punch should be supported and guided by the stripper. Assuming that the punch is of ¼-inch diameter and is to pierce hard rolled stock ⅛ inch thick, the first step is to find the difference in diameters between the punch and the die.

Clearance. The rule for clearance is to multiply the thickness of stock in thousandths of an inch by .06; the answer being the difference in thousandths of an inch between the punch and the die.

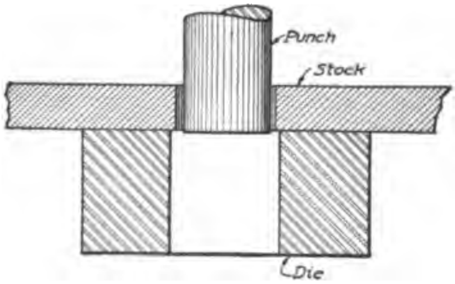


Fig. 1. Section of Die in Which Soft Stock Is Used

Whether to increase the size of the die or to decrease the size of the punch depends upon the nature of the stock and whether the piece punched out must be of a certain diameter or whether the diameter of the hole must be maintained. If the blank or piece punched out must be of a certain diameter, say .250 inch, then the die is made .250 inch, whereas, if the hole pierced is to be maintained .250 inch, then the punch is made .250 inch in diameter, and the clearance or difference between the punch and the die is obtained by increasing the size of the die. This is only essential, however, where the diameter of the hole or of the blank is to be maintained in thousandths of an inch.

Resistance of Sheets. When punching holes in sheet metal, the actual diameter of the blank, using the same die and punch, varies with the temper of the stock. For instance, on hard rolled stock the blank would break somewhere between the diameter of the punch and that of the die as exaggerated in Fig. 1. This is more

noticeable on heavy stock as the thick stock is stiff enough to withstand the pressure of the punch. If soft stock were used in a die as in Fig. 1, the stock would bend down between the punch and the die, causing a heavy burr on both the blank and the hole. A tight-fitting punch and die also causes heavy burrs on both hole and blank, when punching thick stock

Binding. The main reason why a difference in the diameters of punch and die for piercing thick stock is necessary is to prevent breaking the punch. If a punch that snugly fits the die were used to pierce ¼-inch stock, the stock would be such a tight fit on the punch that it would be hard to strip the stock from the punch. Again, the severe rubbing of the punch as it passes through the stock would cause the punch to roughen, or, to use the shop term, to pick up, which causes the stock to stick to the punch, and which is one cause of the punch breaking.

Another cause of breaking, and one which the die-maker must guard against, is when the underside of the stripper, where the stock comes in contact with it in stripping, is not parallel with the die, or rather is not at right angles with the travel of the punch. It is readily seen that, if ¼-inch stock is snugly gripping a small punch and the stock comes in contact with the underside of a stripper plate which is on an angle, the stock is going to adjust itself to the surface of the stripper, which will snap off the end of the punch.

Guiding. Following the rule for clearance given above, we find the difference between the punch and the die to be .0075 inch, and, assuming that the punch is of small diameter, it now becomes important which part is made first, as the punch should be guided and supported. The term guided, when applied to a punch attached to the ram of a power press that travels in a positive channel, appears at first glance to be a misnomer, but any uneveness of the stock surface, such as caused by a slight kink in the stock or even by a piece of foreign substance on the stock, causes the punch to be deflected from its line of travel, resulting in a broken punch.

Sequence of Operations. *Making Die Bushing.* The sequence of operations for one good method of making the punch and die, Fig. 2, is to cut off a piece of round tool steel for the bushing *a*, Fig. 2, say 2 inches longer than desired, and, gripping the steel in a lathe chuck, to rough-drill the hole to within, say, $\frac{1}{32}$ inch of size,

then to turn the outside diameter to the desired dimension, and finally to bore the hole to the desired size. Boring and turning at the same setting insures concentricity of the hole and the outside, providing, however, that one diameter is not finished before starting to machine the other diameter. For instance, if the outside were turned to exactly the right diameter, then the hole spotted, drilled, and bored, the pressure of spotting and drilling might cause the rod to spring or to shift in the chuck, resulting in the finished hole being eccentric with the outside. The tool-maker must constantly guard against any element of chance.

After both diameters are obtained, the bushing is cut from the rod, using a cutting-off tool in the tool post of the lathe. The clearance in the bushing can be bored by setting the slide rest at the desired angle, say ½ of a degree—the shop term for expressing 0° 30′. If a taper reamer is employed, we have no assurance that the finished taper hole will be concentric with the outside, as the reamer can be started on an angle with the hole. The bushing is now hardened and drawn to a dark straw color.

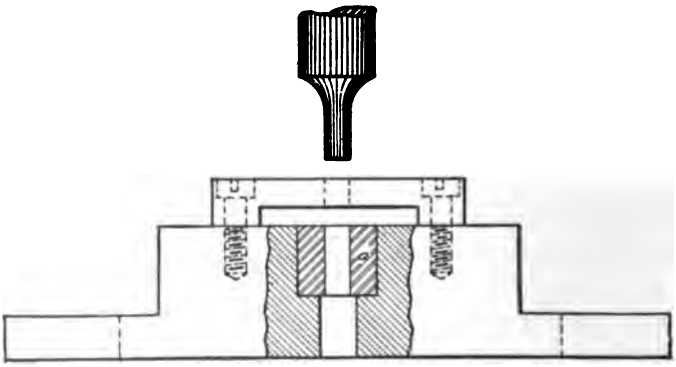


Fig. 2. Punch and Die Showing Use of Die Bushing

Making Die Shoe. The next step is to plane the bottom of the die shoe. As the top and bottom surfaces of die shoes must be parallel, it is obvious that we must hold the die shoe by clamping it to the bed of a shaper or on the faceplate of a lathe. If gripped by its rough sides in a shaper vise, difficulty would be experienced in obtaining parallel surfaces.

Alignment of Stripper. After machining the top surface of the shoe, the bushing is inserted. At this point is where the die-maker must be careful on this particular job. The haphazard trust-to-chance method is to drill and counterbore the hole for bushing, drive in the bushing, attach the stripper by means of screws, then put the hole in the stripper by transferring through the hole in the bushing.

The more accurate and workmanlike method is to make the punch after machining the top surface of the shoe, then to make and attach the stripper to the die shoe by screws and well fitting dowel pins. Lay out and prickpunch on the stripper face approximately the desired location for the die hole, and strap the die shoe to the faceplate of the lathe. It should be remembered that whenever any work is clamped to the faceplate of any machine, the faceplate with the work attached is always to be revolved one complete revolution by hand to make sure that projecting corners of the work clear all parts of the machine; this will prevent many accidents.

Indicate the prickpunch mark to be comparatively true. The shop phrase *indicate* means to place the contact point of a test indicator, as shown in Fig. 3, against the work, and, when the work is properly located, the indicating pointer will not deviate from a graduation on the arc. Graduations on test indicators are usually so spaced that their intervals represent one one-thousandth of an inch each. If the indicating pointer moves two graduations during one complete turn of revolving work, it means that the work is actually out of true only one one-thousandth.

Spot the stripper and drill the hole clear through both the stripper and the die shoe. Then bore the hole in the stripper to fit that portion of the punch that enters the stripper. The stripper is now removed, but the die shoe is not disturbed, and the hole for the bushing is bored in the die shoe to a driving fit. The reasons for boring the stripper are many. First, we can make the hole fit the punch, which would not be so easy if the hole in the stripper were drilled—the drill being guided by the hole in the die which would be somewhat larger than the drill. It is obvious that the hole in the stripper might not be directly in line with the hole in the bushing. Again, by drilling through the die shoe the shoe would rest either on the screw heads on the stripper, or on the face of the stripper, or on the parallels, any one of which may cause the drill

to pass through the stripper on an angle. Granting that the parallels, or whatever is used, will insure the bottom of the die shoe

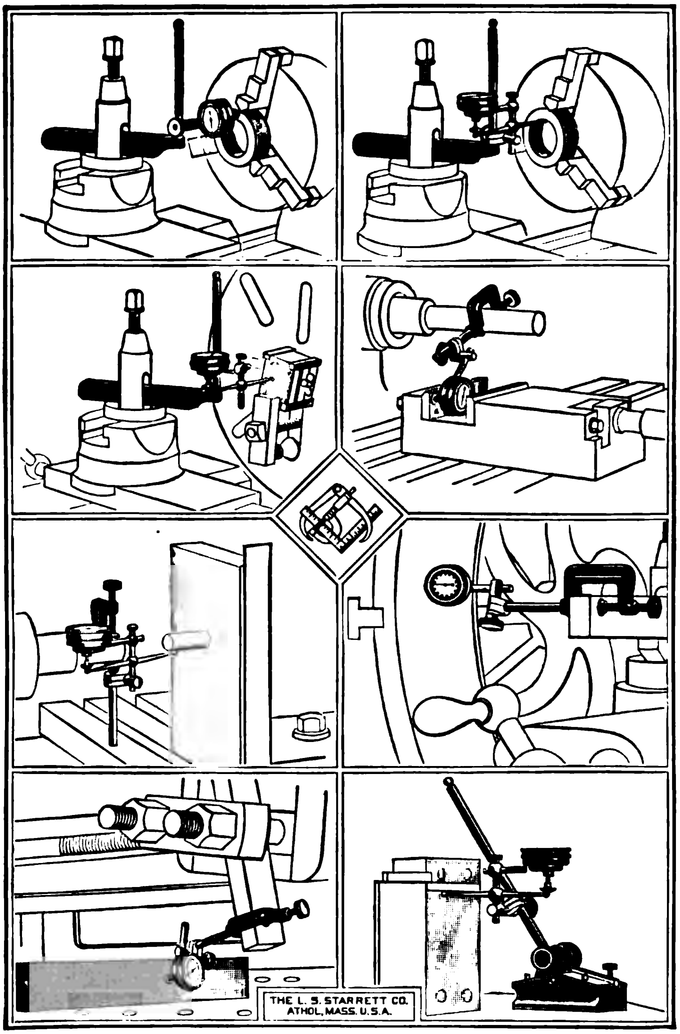


Fig. 3. Various Positions of Test Indicator in Shop Work
Courtesy of L. S. Starrett Company, Athol, Massachusetts

resting parallel with the table of the drill press, it does not follow that the table of a much abused drill press is at right angles with the travel of the drill-press spindle, and the hole that is drilled and

reamed through the stripper may be at an angle, so that when the die is set up for work in the press the punch will have to spring every time it passes through the stripper, which will eventually cause breakage of the punch.

It is attention to these apparently unimportant details that distinguishes the master workman from the ne'r-do-well class. At first glance, the punch and die shown in Fig. 306, Tool-Making, Part III, looks insignificant—all that is necessary apparently being simply to turn up a round piece, bore out a round hole, attach a strip across the top, and the die is complete—and on some classes of work this is true, but that same simple die may be called upon to perform work that requires greater care in die-making than the haphazard method.

Irregular Shapes

Question of Steel. *Sheet Stock.* Fig. 307, Tool-Making, Part III, shows that type of die known as an irregularly shaped blanking die. When making this die the die-maker should follow the blue print absolutely, unless, of course, he discovers an apparent mistake, in which case the foreman's attention should be called to the fact. If a blue print is furnished, the dimensions and the horizontal angle at which the die is to be laid out appear on the print, but if no drawing is furnished, the die-maker should first of all ascertain what width and what thickness of stock is ordered for the job, as the width of the stock governs the angle at which the die must be laid out on the die block.

The angle of the die in relation to the die block is very important, if the blank is to have subsequent bending operations, due to the fact that in rolling the sheet stock there is an actual grain, and bending the blank with or across the grain is almost analogous to bending wood. A piece of sheet stock can be bent at right angles having a sharp corner, if the bend comes crosswise of the grain, but if the bend is made lengthwise of the strip, the stock will break. Therefore, a die-maker, knowing this, should not proceed with a die unless he has full information. This is another instance of eliminating every element of chance or, that other bugaboo, of taking things for granted.

Die Stock. Assuming that the blank is to remain flat and that the sheet stock is ordered just wide enough to punch one blank from

the strip, the first move is to select the die steel, for it is absolutely essential when hardening the die to know what brand of steel the die is made from. Some makes of tool steel are more expensive than others, and certain makes are made to harden in oil which prevents distortion to a great extent, while if the oil hardening steel were hardened in water, the die would crack. On plain dies, such as Fig. 4, any good grade of carbon steel which is lower in cost will answer, as there are no delicate points on the die to distort or to present chances of cracking. If there is no distinguishing mark on the steel, it is best to cut a small piece from the bar, drill several holes in it, and use it as a test spiece, hardening it in water.

Preparing Die Block. Having ascertained the brand of steel, the block is cut from the bar, and the first surface to be planed or milled should be the widest surface; this giving a broad bearing for the machined surface to rest against the solid jaw of the vise. The edge is next machined, then keeping the broad machined surface against the solid jaw, the block is turned so that the edge just machined rests on the bottom of the vise. We now have two machined surfaces resting on two machined surfaces of the vise, and the other edge is machined. A pair of parallels are placed on the bottom of the vise, and the broad finished surface is placed on the parallels, which causes the two machined edges to come in contact with the vise jaws. We now have three machined surfaces to position the block when machining the other broad surface. At least one end of the die block should be machined at right angles, or to use the shop term, machined square with the edges. The object in machining the end is to aid later in laying out.

Working Face. Whichever side is to be used for the top or working face of the die should have at least $\frac{1}{16}$ inch of stock removed, due to the fact that in hot rolling tool steel the outer surface becomes oxidized and is decarbonized to a certain extent, and, unless enough stock is removed to get under this burned surface, the die may cause trouble in hardening as the top surface may be soft in spots, in connection with which, if the die is rehardened in an attempt to obtain an entire hard surface, the repeated hardenings invariably produce cracks in the die. If a die, after the first hardening, should appear soft in spots, it would be better to draw the temper and to grind, say, $\frac{1}{32}$ inch from the top surface in order to remove all burned

metal. If the decarbonized surface caused the soft spots, the entire surface of the die would be hard after grinding, and rehardening would be unnecessary. Also, prior to laying out the die, the top surface of the die block should be machined very smooth and should

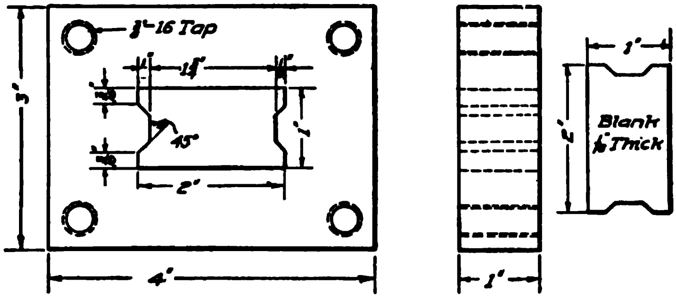


Fig. 4. Drawing of Piece to Be Prepared

be further smoothed with emery cloth. Instead of laying the grain one way when using emery cloth, it is better to polish with a circular motion, as lines scribed on the die are more pronounced over circular emery marks than over straight ones. When nicely smoothed

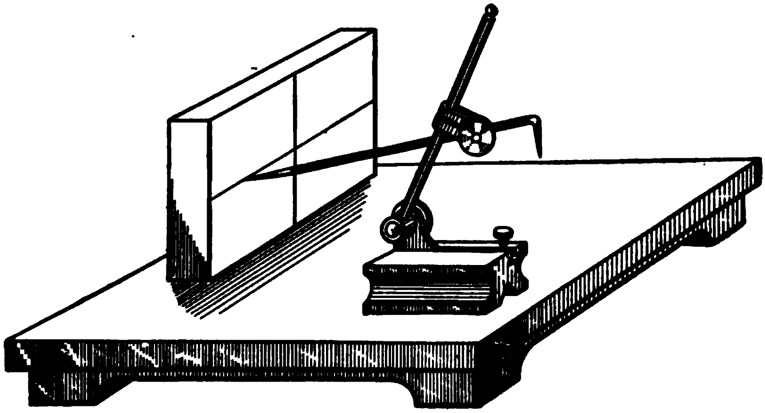


Fig. 5. Scribing Center Lines on Block

the surface should not be touched, especially with the fingers, as grease marks interfere with the proper bluing of the surface.

The block is now placed, polished side up, over a forge and heated slowly until a deep blue appears on the surface, at which point the color is set by quenching, preferably in oil. A scribed line is more

pronounced on a blue surface than if a copper-sulphate blue-vitriol solution is used, and another objection to the coppered surface is that it peels off when drilling and filing the die, which removes the scribed lines. The die block is now ready to lay out.

Laying Out Die. If a templet or model blank is furnished from which to make the die, then the clamp shown in Fig. 332, Tool-Making, Part III, is used to securely hold the templet on the face of the die block while the outline is traced with a fine sharp pointed scriber. If, however, a drawing, Fig. 4, of the piece is furnished, the first step is to scribe center lines on the block as in Fig. 5, in

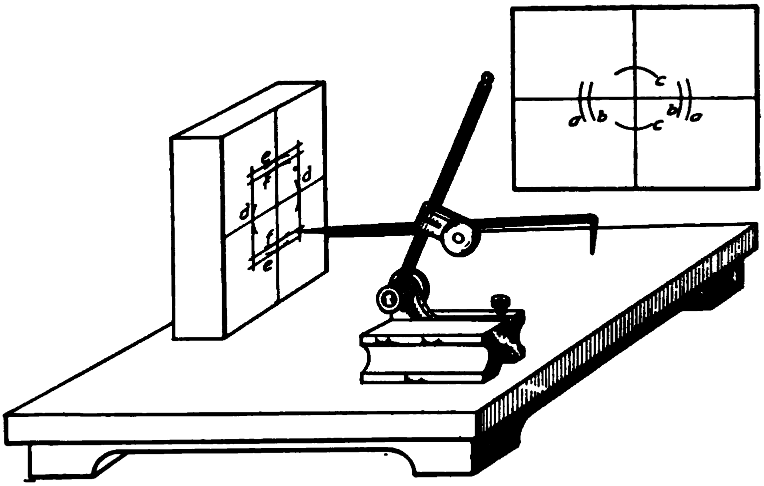


Fig. 6. Method of Scribing Center Lines

order to transfer the outline, as shown on the drawing, to the face of the die.

Referring to the drawing, Fig. 4, we note that the overall length is 2 inches and the width is 1 inch. A fine prickpunch mark is placed at the intersection of the lines, the divider points are set 1 inch apart, and a section of a circle is scribed at each end as at *a*, Fig. 6, and, by again referring to the drawing, it is noted that the inside dimension is $1\frac{3}{4}$ inches. The dividers are set at one-half this —$\frac{7}{8}$ inch—and the lines *bb* are scribed. The width being 1 inch, the dividers are set at $\frac{1}{2}$ inch and the lines *cc* are scribed. The lines *dd*, *ee*, and *ff* are now scribed, using the surface gage or scratch block as at *B*, Fig. 6. This is why one end of the die block was

machined at right angles to the edges when machining. A square can be used instead of the surface gage, but it is not quite as handy. The angle lines are scribed by setting the protractor at 45 degrees and scribing along the blade, as at Fig. 7.

Shaping of Die. *Roughing Out.* If a die filing machine, Fig. 319, Tool-Making, Part III, is at hand, a narrow hack-saw blade is placed

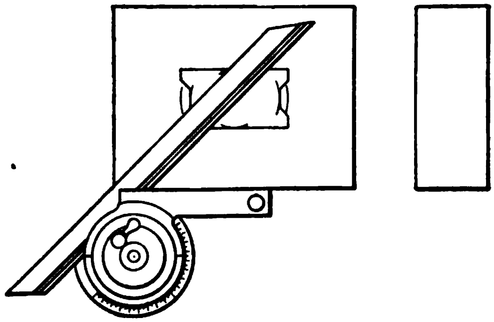


Fig. 7. Scribing Lines by Means of Protractor

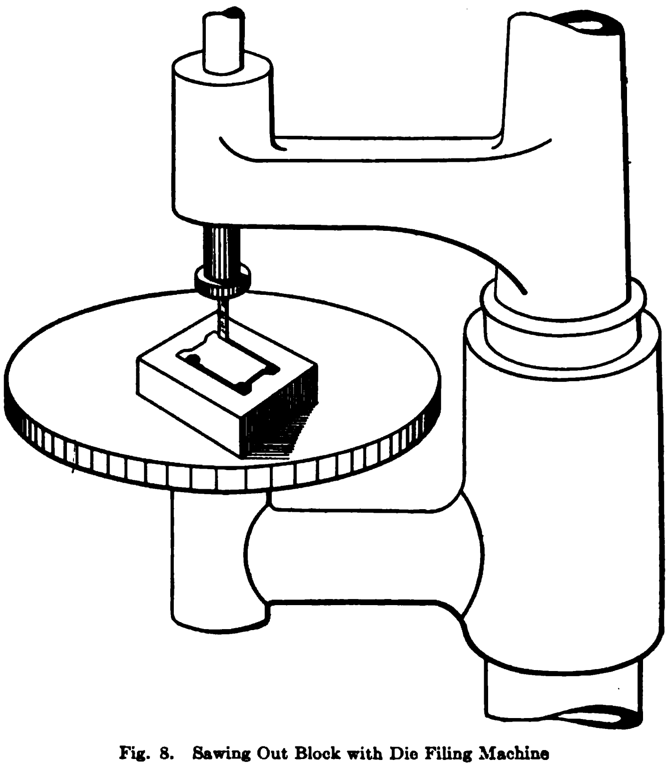


Fig. 8. Sawing Out Block with Die Filing Machine

through the hole drilled in the corner of the die, and the blade with teeth pointing downward is secured in place of the file, as

in Fig. 8. By tilting the table the desired angle the piece in the center of the die can be sawed out very close to the line, with the desired clearance, which leaves very little to file. If a die filing machine is not used, the center piece is removed by drilling a series of small holes just inside the line and by cutting out the

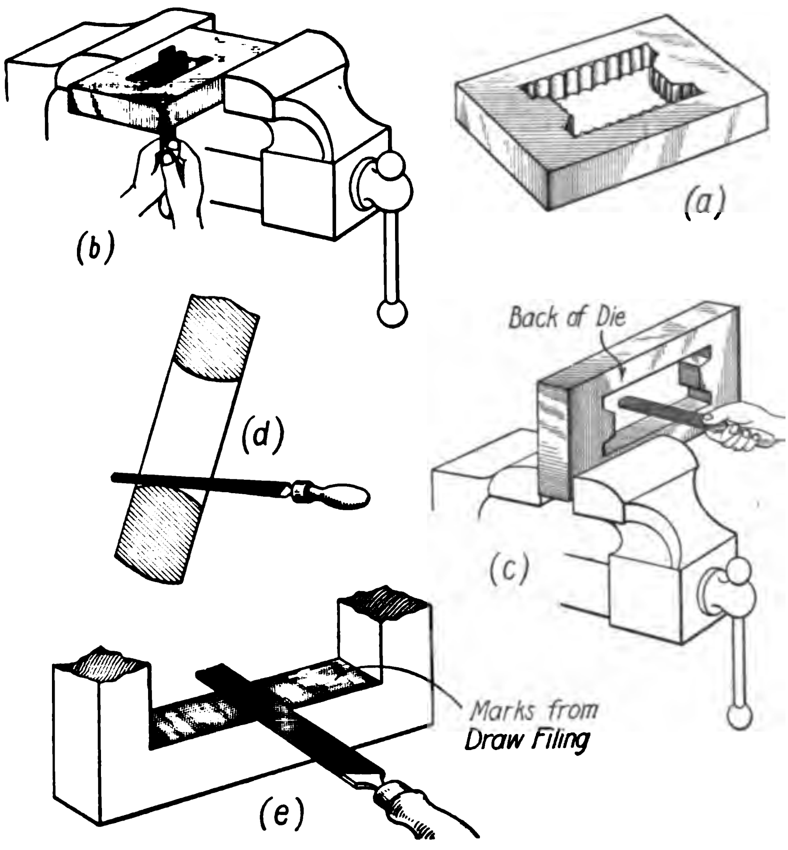


Fig. 9. Die Block in Various Stages of Completion

web between the holes with a broach, as described in connection with Fig. 312, Tool-Making, Part III. After the broach has been driven nearly half way through from both sides of the die, the center piece can be forced out. The die then looks as in *a*, Fig. 9.

The webs between the drilled holes can be removed easier and quicker by means of a cold chisel and hammer than by filing, but

great care must be exercised when using a chisel, for there is danger of cutting too deeply. After the greater part of the webs are removed, the die is gripped in the vise in a horizontal position, top side up, and with a coarse file the remaining webs are removed by filing up and down as indicated in *b*, Fig. 9. Filing in this position has several advantages, but for final-filing to line and to straighten the filed surface better results are obtained by filing crosswise as in *c*, Fig. 9.

The most expert die-makers cannot file a die in one direction without producing a slightly rounded surface as exaggerated in *d*, Fig. 9. As the line is approached in filing, the filed surface should be draw-filed frequently. By filing crosswise, then draw-filing in the opposite direction, the file marks or grain is laid lengthwise of

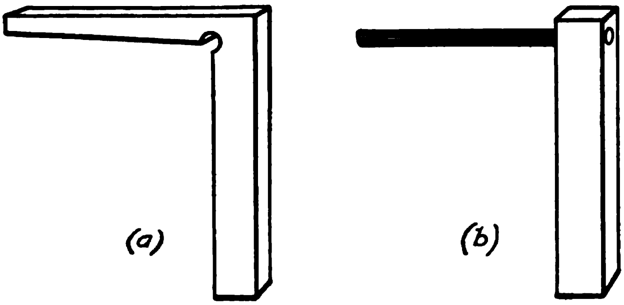


Fig. 10. Die Square

the die, so that as cross-filing is continued the marks lengthwise serve as a guide as to whether the die is being filed straight or not, as in *e*, Fig. 9.

Clearance. As soon as the webs between the drilled places are entirely removed, the clearance of the die should be started. This is aided by using a narrow-blade die square of the proper angle, Fig. 10. These squares are made by die-makers by filing from $\frac{1}{16}$-inch sheet steel, and the blades are about $1\frac{1}{2}$ inches long. Some use a small block with a straight rod inserted as at *b*, Fig. 10. When the opening is filed so that the scribed outline on the face of the die is partly filed away, the filed surface through the die should be carefully tested with a knife straightedge to make sure that the cutting edge or the top of the opening is not wider than the opening midway

through the die. By using a fine file or a flat scraper, the filed surface can be made very straight.

Compensating for Bulging. If the shop practice is to have only ½ of a degree clearance, it means that the opening through the die will have almost parallel walls. Attention must be paid to these walls if the die is somewhat heavy or thick, as there is a bulging effect in the opening when the die is hardened, as shown at *a*, Fig. 11. This is probably caused by rapid contraction of the exterior surfaces of the die when immersed in the bath, and this contraction compresses on a comparatively soft interior, as the interior is red hot. To guard against the bulging, the walls of die should be scraped

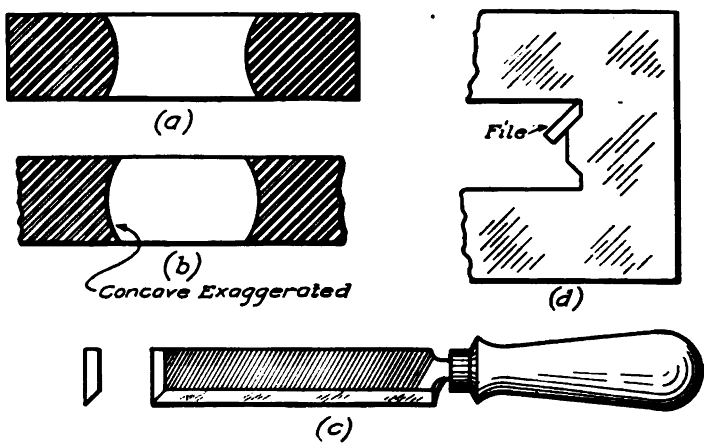


Fig. 11. Sketches Showing Method of Compensating for Bulging and of Filing Corners

slightly concave, as shown at *b*, Fig. 11. It is readily seen that, if the walls are almost parallel and then they bulge toward each other during the hardening process, a blank would not pass through the die without distortion of the blank.

Filing Corners. When filing the corners of any die, the file must have a smooth edge in order to preserve the corner. Again, when filing an angular surface as on the die in question, it is good practice to grind the file as at *c*, Fig. 11; the smooth part sliding on the straight part of the die. If the file is not ground to suit the angle, the file constantly slides down the angle, and the corner of the file mars the finished flat surface at the end of the die. The die files, as

purchased, seldom are of the right size or shape, and the die-maker must grind the file to suit the job.

Tapping. Referring to the drawing of the die, it is noted that there must be four holes drilled and tapped for $\frac{3}{8}$—16 screws. As the die is of tool steel and also since it is to be hardened, a full thread is not necessary, and a $\frac{5}{16}$-inch drill will leave ample stock. After all holes are drilled and tapped, the die should be carefully checked with the drawing to make sure that all holes are in the die.

Hardening of Die. The next step is to harden the die. The hardness of a die or of any piece of tool steel depends largely upon the degree of heat to which the steel is heated, and upon the rapidity of cooling. For instance, three pieces of carbon steel, Nos. 1, 2, and 3, are all heated to the same degree of temperature. Piece No. 1, immersed in a bath of oil, would not be as hard as piece No. 2, immersed in water. If piece No. 3 were dipped in a bath of mercury and allowed to cool in the bath, the piece would be harder than those dipped in oil or in water. Mercury has a higher heat conductivity, therefore the heat in the die is dissipated more rapidly with such a bath, causing a greater hardness. Starting with the three pieces at same temperature and obtaining three degrees of hardness shows that it is the bath that plays an important part.

Corner Protection. Knowing that the dissipation of heat in the die plays a prominent part in hardening, we must then guard against the effect of holes in the corners of the die. If the die were dipped with the tapped holes open, the water or bath of course would fill the holes, and the heat would be conducted away faster from the corners than if the holes were not there. Therefore, it is good practice to fill the screw holes, or any hole that comes near a corner, full of asbestos before heating the die; this eliminates some of the chances of cracking. If the holes were left open and a free circulation of water passed through the holes carrying away heat from the die, and the outside surface of the corner were also in contact with or immersed in water, the contraction of the corner would be so much more rapid than that of the main portion of the die that, when the main portion continued to contract, it would cause a tremendous strain between the portion contracted and the portion contracting, which would result in a crack. The corners invariably drop off if not plugged with asbestos. Fire clay is sometimes used,

but it is not good practice, for the water in the clay is driven off when heating the die and the clay shrinks and drops out of the hole.

Tempering. Assuming that the die is ready to harden and having the screw holes plugged—with a soft machine screw if desired—the die is heated slowly and evenly in a muffled fire preferably. A blast such as a black smut forge would cause uneven heating of the die, which means uneven expansion. If either an open forge or a muffle furnace is used, the position of the die should be constantly changed to insure even heating, and the face of the die should be up. When an even temperature of the desired degree is obtained—varying with different makes of steel—the die is gripped by tongs, plunged into the bath, and moved slightly up and down, keeping it fully submerged at all times.

The die should not be allowed to remain in the bath, however, until it becomes cold, because some parts of the die will contract faster than others. When the violent vibration on the tongs ceases, the die should be removed and plunged into an oil bath as quickly as possible. This is done to allow the heat from the heavier portions to flow into the parts that are cooler, causing a more even contraction. The die should be removed from the oil bath before the die is cold, it should be drawn to the desired temper immediately and, to allow it to cool slowly, should be set on some material which is of low heat-conductivity. If a hardened die, while hot, were set on a cold mass of steel, the chances are that cracks in the die would result.

Finishing of Die. After the die is thoroughly cool, the oil and scale are removed, and the face that is most level is placed against the grinder bed and the other face is ground. The bottom of the die need only be ground until a true surface is obtained, but the top or cutting surface should have several cuts taken across to remove any burned metal that may have been caused in hardening and also to insure the cutting edge being keen its entire length.

Laying Out Punch. The next step is to make the punch. Assuming that the blanking punch has been machined, the bottom or cutting surface is blued in, the same as the die, the punch is clamped to the face of the die as at Fig. 12, and the outline of the die is transferred to the face of the punch. A very slender and sharp-pointed scriber must be used, and after the entire outline is scribed, the line

must be inspected carefully before the clamp is removed. It is easy to make an error in transferring the outline, as the die is quite thick and the scriber must of necessity be tapering, and the largest diameter of the scriber can rest against the die instead of the point of the scriber being in contact with the cutting edge of the die.

If the die has narrow places where it is not possible to scribe the line, then the surface of the punch is coated with solder and machined level, and the outline of die is transferred by forcing the solder into the die.

Forming of Punch. *Shearing Method.* The punch is now gripped by the shank in the chuck of a milling machine—the shank having been turned on the punch for two reasons: to facilitate milling the punch to shape; and to act as a heavy pilot to stiffen the punch on the punch plate. After milling to within, say, $\frac{1}{64}$ inch of the line, the punch is removed and the entire cutting edge of the punch is beveled slightly, and, placing the punch in the die opening, the punch is forced in far enough to obtain the exact outline of die. This operation is called *shearing the punch.* The punch can then be replaced in the chuck of the milling machine, and by skillful workmanship all surplus metal can be milled away, leaving only a small amount of hand work necessary to complete the punch. If the punch is milled after it has been sheared in the die, a narrow cutter must be used to remove the small and surplus stock. A safer way for the beginner—in fact, many experienced die-makers pursue this method—is to chip the stock away, shear the punch again, and the stock that the cutting of the die causes to curl up is again chipped and scraped away, then repeating the operation until the punch is fitted the desired depth.

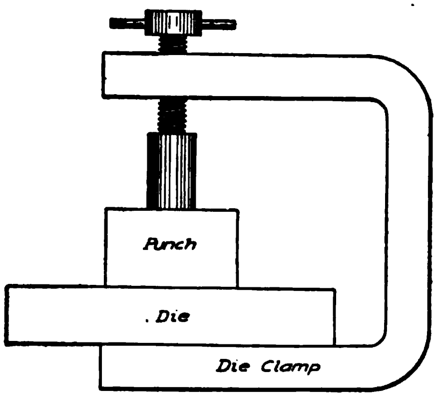


Fig. 12. Laying Out Punch

One point that is essential when shearing a punch in the die is to make sure that the punch enters at right angles with the face of

the die and also that the punch cannot tilt when being withdrawn. Any tilting when withdrawing will surely break off the weak corners of the die. Therefore, it is best to secure the punch in the ram of a press and to fasten the die securely to the bed when shearing.

Punches and dies having no weak corners or points can be sheared by forcing the punch in the vise but the edge of the punch will be rounded off when driving out the punch, if great care is not exercised, as one end will invariably drive out ahead of the other.

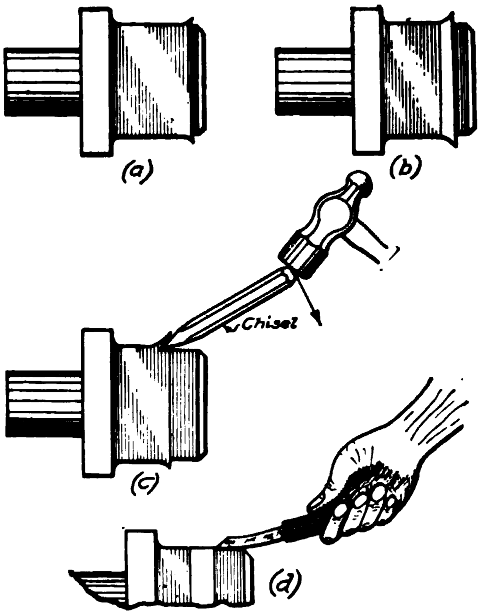


Fig. 13. Chipping Away Surplus Stock on Punch

In Fig. 13 at *a*, *b*, and *c* the punch is shown as it appears at the first, second, and third shears. The punch should not be forced in more than $\frac{1}{8}$ inch at a time, as the die does not actually cut the metal away, but crowds it out, and, after a certain amount of stock is banked up on the punch by the crowding or pushing action, the stock tears away from the punch and deep spots will be torn in the punch that are below the size of the die. For chipping away the surplus stock, the chisel should be ground so that it does not have a tendency to dig in, and the chisel should be struck as shown at *c*, Fig. 13.

After each shearing operation and chiseling away of stock the surface is smoothed by scraping, *d*, Fig. 13, and by filing. Only the point or end of the file must be used, or else the cutting edge of the punch will be filed tapering or too small. The entire surface of the sides of punch must be reduced to less than the size of the die, governed by the thickness of metal to be punched, and the surfaces should be made smooth.

Finishing. If the punch is to be secured to the punch plate by screws, the holes are drilled and tapped in the punch by transferring the holes from the punch plate.

The punch is now gripped by its shank in a lathe chuck and the beveled edge is faced off, leaving a sharp corner or cutting edge, after which the punch is hardened. Punches are not made as hard as dies, and a deep dark straw color or even purple proves satisfactory for stock that is not tempered by heating and dipping. For punching thin soft metals—aluminum, copper, or brass—or paper, the punch is generally left soft, for there must be a close fit between

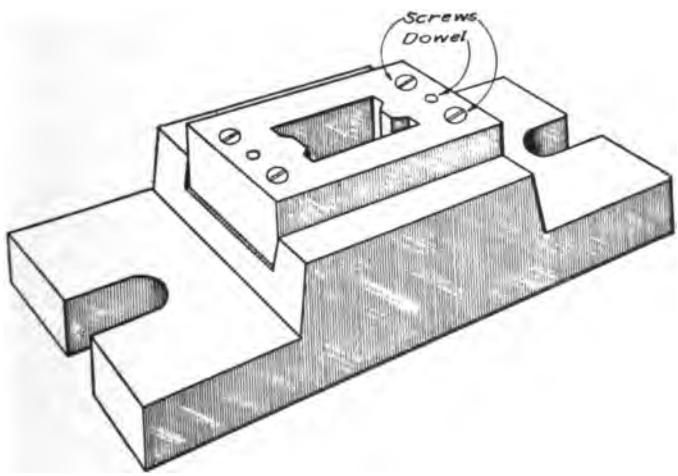


Fig. 14. Die Fitted Tight in Die Shoe

it and the die in punching thin stock, and when the punch becomes dull, which is caused by its rubbing through the material being punched, it can be upset or riveted slightly around the edge and sheared into the die without taking the punch from the press. This insures a perfect fit between the punch and the die which is essential on very thin stock.

After hardening, the punch is attached to the punch plate, and the cutting face of the punch is ground by resting the back of the punch plate against the bed of the grinder. This insures the face of the punch and the back face of the punch plate being parallel.

Stripper. The stripper is now fastened to the die without the guide strip *D*, Fig. 307, Tool-Making, Part III, so that the stripper

comes in contact with the face of the die. The outline of the die is now transferred to the stripper, and the stripper then is removed and the opening drilled and filled, much the same as for the die, except that the opening in the stripper is generally made somewhat larger on large blanking punches.

Die Shoe. The adjustable die shoes shown in Figs. 308, 309, 310, and 311, Tool-Making, Part III, are designed more for a jobbing shop where quick changes are made, that is, where only a few blanks of each kind are made at a time; but for continued daily production it is better to fit the die tight in a recess in the die shoe, as in Fig. 14, and to have a separate die shoe for each die. The first cost of making the die shoe for each die is soon wiped out by the saving of the pressman's time in changing the dies from one shoe to another.

SUB-PRESS DIES

Typical Features. Plain blanking dies as described this far are of the simpler type and are used only where a variation in blanks is permissible, for any die that allows the blanks to pass clear through is given clearance, and each time the die is ground the die becomes larger. With sub-press dies—sometimes called compound dies—the outside diameter or size of blank does not change, as the dies are made without clearance, for the blank only enters the die about half the thickness of the stock being punched, then the blank is forced back into the strip.

Before entering upon the making of a sub-press die, it is well to thoroughly understand the working of this type of die which in some instances is quite complicated. The term *sub-press die* means that the punch and die are mounted in a sub-press, or, to make it plainer, the punch and die work within a frame which has a babbitted bearing to guide the plunger to which the blanking die and piercing punches are attached, and this frame or sub-press is in turn actuated by a power press.

Fig. 363, Tool-Making, Part III, is an excellent illustration of the working principle of sub-press construction in its simplest form. Bear in mind that this die is a sub-press in principle only. Referring to this illustration it is noted that the blanking die A is mounted on the upper portion, which is characteristic of all sub-press construction. The blanking punch B also contains the piercing die C,

and inside the blanking die A and surrounded by the upper stripper E is the piercing punch D. The lower stripper F surrounds the blanking punch.

Operation. In operation the stock is placed on top of stripper F, and as the upper portion descends blanking punch B enters blanking die A, causing stripper E to recede. At the same time that the blanking punch enters the die, piercing punch D enters piercing die C in the blanking punch. In fact, all parts interlock. The blank is forced into die A, and the scrap punching passes down through hole C. As the upper section ascends or separates, strippers E and F move toward their original positions, due to spring pressure, just as fast as the upper section ascends. The result is that the blank is forced back into the strip by both strippers.

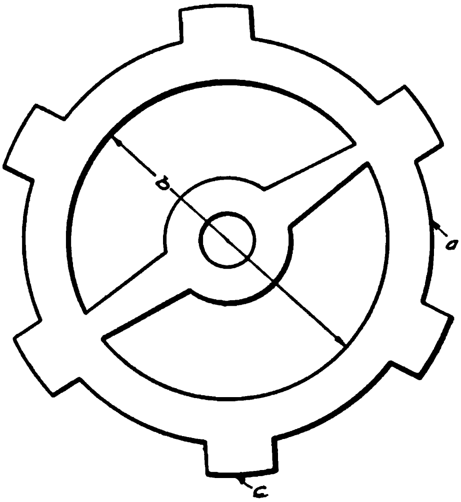


Fig. 15. Blank Produced by Sub-Press Die

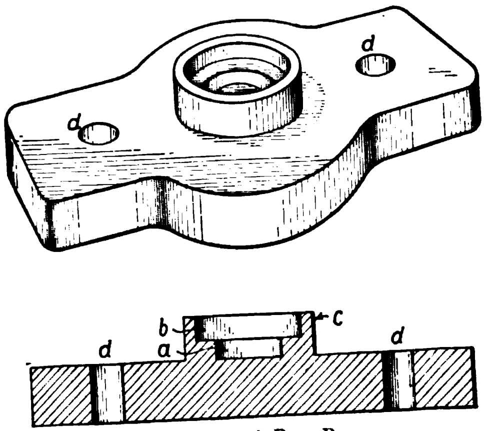


Fig. 16. Sub-Press Base

While the die shows only the principle and would blank a washer at each stroke, it can be readily seen that the blanking punch and die can be of any shape and that a number of piercing punches may be employed. Any one of the sample punchings shown in Fig. 379, Tool-Making, Part III, is made at one stroke, and the clock plate shown has thirty-four separate piercing punches.

Making Press Body. To make a sub-press die to produce the blank shown in Fig. 15—the balance wheel of a clock—looks at first glance to be a difficult job, but in reality it is simple, and the die can be made without touching a file to it except to remove a few burrs. The sub-press base, Fig. 16, is made by first planing the bottom, then, strapping to a lathe faceplate, the top face is turned

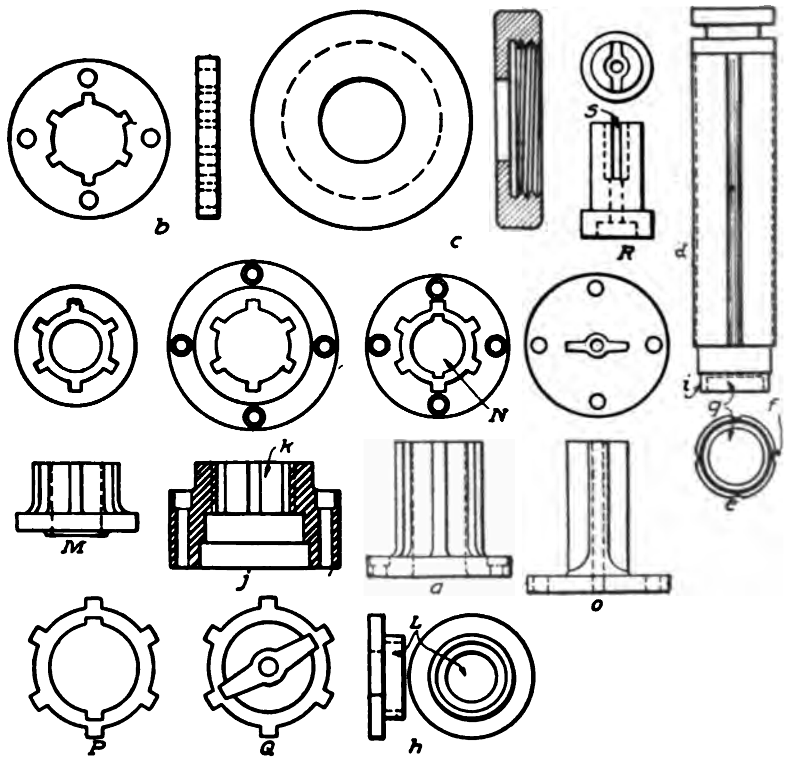


Fig. 17. Sub Press parts: *a*—Blanking Punch and Piercing Die; *b*—Lower Stripper; *c*—Press Frame Cap; *d*—Plunger; *h*—Punch Holder; *j*—Blanking Die; *M*—Upper Stripper; *o*—Crossbar Punch; *P*—Section of Blanking Punch; *Q*—Section of Assembled Blanking Punch; *R*—Piercing Punch

level and the recesses *ab* are bored. The recess *a*, Fig. 16, is the seat for the blanking punch *a*, Fig. 17, and the large recess *b*, Fig. 16, receives the lower stripper *b*, Fig. 17, for the blanking punch.

The frame *a'*, Fig. 18, is next machined by gripping the end *b* in a lathe chuck and facing off the bottom, and boring the recess to a good push fit for the outside of flange *c*. The inside of the frame

must be bored tapering, but not while gripped in chuck, for the frame is thin and that portion gripped is slightly distorted, and the inside it would not be round when the chuck pressure is released.

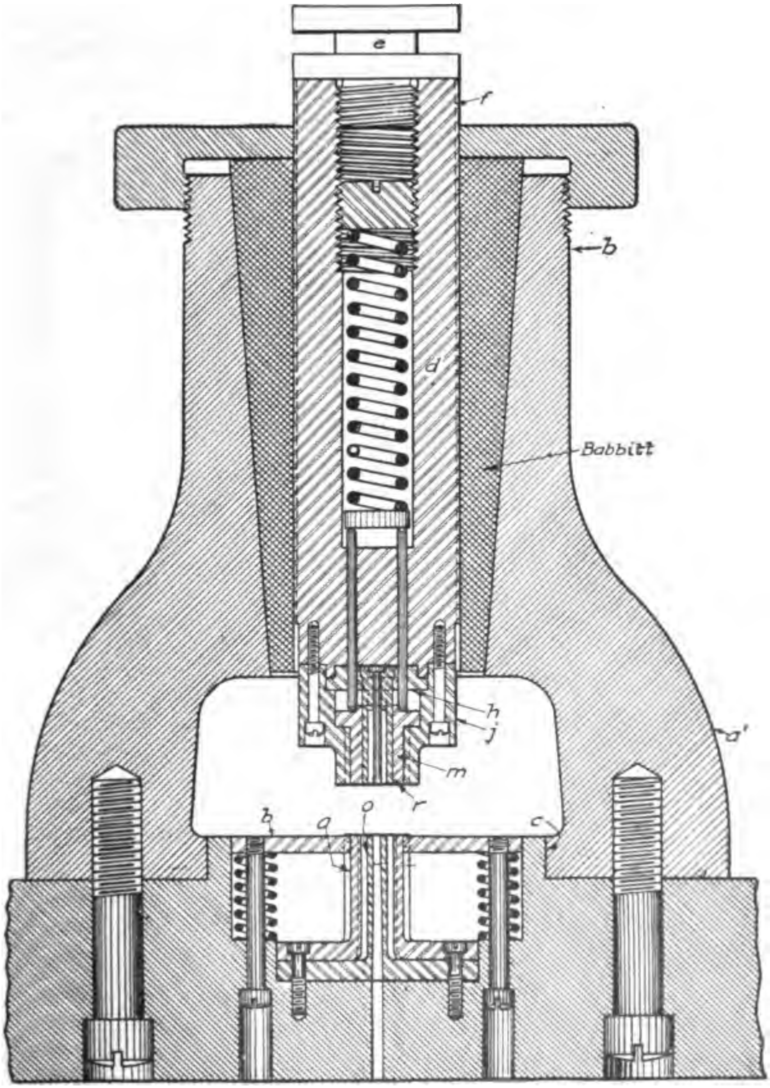


Fig. 18. Details of Sub-Press Punch and Die for Fig. 15

The base, Fig. 16, is now drilled as at *dd*, the frame is placed on the base, and the holes *dd* are transferred to the frame. The

holes in the frame are tapped, the frame is removed, and the holes are slightly countersunk to remove all burrs to insure the frames resting level on the base. The base is then returned to the faceplate of the lathe, and the flange *c* indicated to run true—the base must be attached to the faceplate so that both, if possible, or at least one of the screw holes in the base comes opposite a slot in the faceplate. The frame is then pushed on the base and the screws put in from the back, securely holding the frame to the base. In this position the inside taper bore of the frame is bored, and the end is threaded to fit cap *c*, Fig. 17—previously threaded—at the same setting, and the end of the frame is faced off.

After the hole is bored a splining tool is placed in the tool post and the spindle locked by means of the back gears, and a groove is splined lengthwise of the bore by sliding the carriage back and forth. Light chips must be taken until a groove about $\frac{1}{16}$ inch deep is made. The spindle is rotated one-half or one-third and one or two more grooves are splined. These grooves are simply to prevent the babbitt from turning, and the accuracy of the spacing is immaterial.

The cap *c*, Fig. 17, is now screwed on the end of the frame, the edges smoothed by turning, and the hole bored to the desired diameter, which should be a sliding fit for the plunger *d*, Fig. 18. This completes the lathe work on the base, frame, and cap.

Making Plunger. The button *e*, Fig. 18, is next made on centers and the thread chased. Then the plunger *d* is made; being roughly turned on centers to say, within $\frac{1}{16}$ inch of finish size. The long hole in the plunger is now drilled, bored, and threaded, by holding one end in the steady rest and the other end on the live center, a lacing in connection with a lathe dog being used to hold the plunger against the live center. When using a lacing, the faceplate should be loosened several threads, and, after the dog on the end of the plunger is securely tied to the faceplate, the plate is screwed against the shoulder of the spindle, which tightens the lacing and securely holds the plunger against the live center. After the hole is bored and threaded the button is screwed into the end of the plunger, and, placing the dog on the button, the plunger is turned perfectly straight and smooth and so it fits the hole in the cap. The end of the plunger is turned $\frac{1}{8}$ inch smaller in diameter for a distance of 1 inch as in *d*, Fig. 17, and also in Fig. 18.

The lathe spindle is now locked and four unequally spaced grooves *f* are cut in the plunger the entire length but not deep enough to touch the reduced diameter at the end of the plunger. The grooves are to act as guides when babbitt is poured around the plunger, and the object of unequally spacing is to prevent returning the plunger in the babbitt bearing in any position but that in which the punch and the die line up.

The steady rest is now brought to bear on the reduced diameter, the recess *g* is bored for the punch holder *h*, and the shoulder *i* is turned to the desired diameter to act as a centrally locating member for the blanking die *j*. The diameter of the plunger is of course governed by the outside diameter of the blanking die which is attached to plunger, for it is obvious that a die larger than the plunger could not be withdrawn from the frame after the babbitt surrounds the plunger.

The points to be observed in making the plunger are: absolute straightness; grooves perfectly straight and free from chatter marks, and each one of a uniform depth its entire length; and the finished plunger absolutely free from blowholes caused by casting.

Making Small Parts. *Blanking Die.* It is immaterial in which order the remaining parts are made, as they will be only partly finished when turned to size in the lathe. The blanking die *j*, Fig. 17, should be made from the end of a bar gripped in a chuck and the large diameter of the die should be on the outer end, as in Fig. 19*a*, so that the recess can be fitted to the step on the plunger. The hole *k*, Fig. 17, should be bored at the same setting, and the diameter of the hole must be smooth and of the exact diameter desired at *a*, Fig. 15. The die is cut from the rod with a cutting-off tool in the lathe.

The piercing-punch holder *h*, Fig. 17, is also turned on the end of the rod, and the step *L* fitted to the recess in the end of the plunger. The upper stripper *M*, Fig. 17, should be turned on centers as at *b*, Fig. 19, and left on the piece of rod, for the next operation on the stripper is to mill to form the projections on the balance wheel, as shown at *M*, Fig. 17.

Blanking Punch. Instead of making the blanking punch *a*, Fig. 17, solid, then filing out the recess at each side of the crossbar, which would be a difficult job, the blanking punch is turned in the

manner shown in *a*, Fig. 19. The hole *N* is bored smooth to the exact diameter of *b*, Fig. 15, and the outside of the punch is turned to exactly the same diameter as *c*, Fig. 15. The large diameter of the

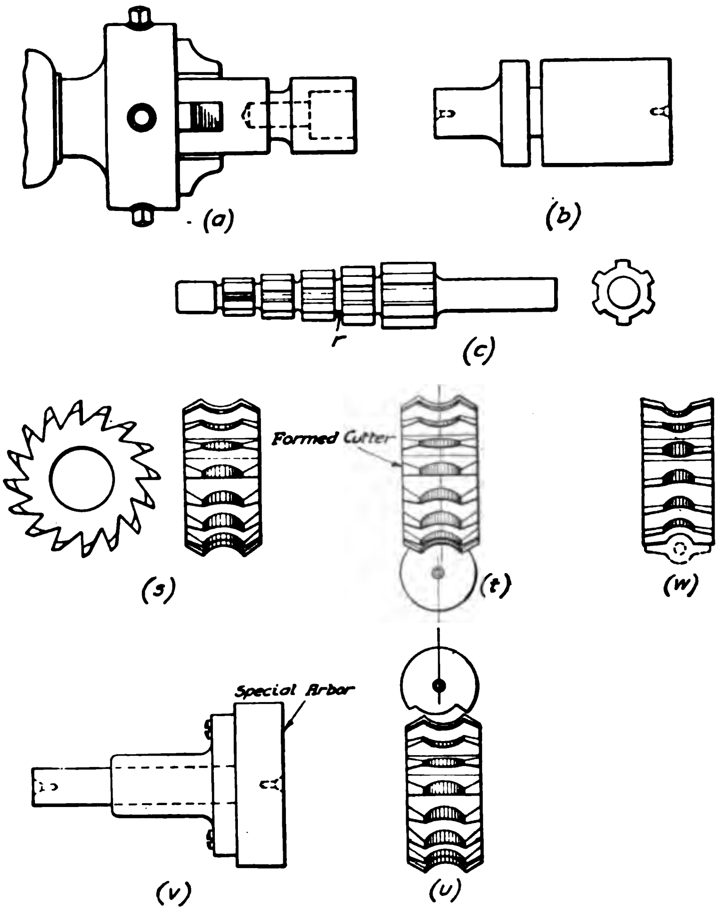


Fig. 19. Broaches and Cutters Used in Making Fig. 15

blanking punch is turned to fit the recess *a* in the base, Fig. 16, after which the punch is cut from the rod.

A die to produce the balance wheel cannot be readily ground to shape after hardening, therefore, an oil-hardening make of steel should be used, which will eliminate many chances of the die changing shape and will permit of machining the parts to exact size while soft.

The piece *o*, Fig. 17, which is milled to the shape of the cross-bar and when completed is inserted inside of the blanking punch, is turned on the end of the rod with the small diameter on the end of the rod. The diameter of the small end must be left $\frac{1}{16}$ inch larger than the hole through the blanking punch, for the blanking punch is splined to a depth of $\frac{1}{32}$ inch on each side, as in the enlarged section at *P*, Fig. 17, to position the ends of the cross-bar as shown in the assembled sketch *Q* of the end view of the blanking punch.

Use of Special Cutters. Before milling the spaces on the stripper and the blanking punch, it is necessary to make a number of broaches, *c*, Fig. 19. The number of broaches being governed by the depth of the projections or teeth. The broaches are turned on centers and the end pilot of each broach is made the same diameter on all broaches, and the pilot must be a good fit in the hole of the blanking die to be broached. The broaches are made in steps as shown, each step increasing in diameter by .005 inch. Chip clearance is provided at *r*. The broaches are numbered 1, 2, 3, etc., and the first step on broach No. 2 is made .005 inch larger in diameter than the last step on No. 1, and so on. The last step of the last broach has the same outside diameter as at *c*, Fig. 15.

A formed milling cutter *s*, Fig. 19, is now used to mill the spaces on the broaches, upper stripper, and the blanking punch. The milling cutter is set as nearly central with the center of the dividing head of the miller as possible. Then a test piece, which may be any scrap piece of steel or brass, is gripped in the chuck of the dividing head and milled as at *t*, Fig. 19. The dividing head is then rotated one-half of a complete turn, which brings the milled portion of the rod on the bottom side. Without disturbing the cross-movement of the table the milling machine knee is raised so that the milling cutter can be matched with the milled shape in the rod. If the formed cutter is not centrally located, it is readily noted, for when the milled rod is turned one-half revolution, the milled surface when matched with the cutter shows just double what the error is, as at *u*, Fig. 19, and by moving the table one-half the space shown between the milled form and the cutter and then milling a new place in the rod and repeating the operation of revolving the dividing head one-half revolution, the cutter can be very accurately set.

Having set the milling cutter central with the head or centers, the broaches are milled, and, without disturbing the setting of the milling cutter, the blanking punch is also milled, as is likewise the stripper *M*, Fig. 17. The blanking punch is held while milling on a special arbor having a shoulder as at *v*, Fig. 19, to grip the flanges of the punch and the stripper, as the small bearing surface in the straight hole in the blanking punch or the stripper would not be sufficient to prevent turning on an ordinary arbor when milling. The broaches are hardened, and then ground on the face by revolving them between centers and using a saucer or cup form of emery wheel.

The die *j*, Fig. 17, is now placed on a level surface in a power press which will permit the broach passing through the die. Entering the pilot of No. 1 broach in the hole in the die, the surface of the die is flooded with heavy oil and the broach is forced through the die. The succeeding broaches in their order are forced through in the same manner. The screw and dowel holes are put in the die, which completes it except for hardening.

The inside piece *o*, Fig. 17, of the blanking punch is milled with a formed cutter as at *w*, Fig. 19. At the same setting of the miller the crossbar for the inside of the stripper is milled, but this bar is made two or three thousandths thinner than the crossbar for the blanking punch. The blanking punch *a*, Fig. 17, is now clamped, face out, to the faceplate of the dividing head, a splining tool is secured to the arbor of the miller, the spindle of the miller is locked, and the two small recesses are splined the entire length of the straight portion of the hole in the punch. The recesses are to receive the ends of the crossbar punch *o*. Care must be exercised in setting the splining tool absolutely central with the center of the dividing head, and the blanking punch must be indicated by the hole so that it is central with the head of the miller.

Fitting Piercing Punches and Dies. It must be remembered that sub-press punch and dies do not enter when in use, therefore all parts can be made straight except the scrap punching dies. Clearance must be given to that part of the die where the scrap pieces or punches pass through, and when the pierced hole is irregular in shape, it of course is filed out. The piercing dies, however, as a rule are too small to permit the use of a die square, and for straight-

ness of side of filed openings or piercing dies the die-maker must depend upon skillful filing. In order to determine whether or not the piercing die has clearance on its entire length, babbitt is employed. The die is warmed slightly and laid face down on a piece of paper which in turn is on a flat surface, and the opening is filled with molten babbitt. When the babbitt is cool it should drop freely from the die if the die has proper clearance. When forced out, there will be polished streaks on the babbitt indicating just where the die has insufficient clearance.

As to fitting the punches of a sub-press die the same method is employed as in connection with the gang die shown in Fig. 37—that is, making and inserting the round piercing punches first and using them as guides, then as each irregularly shaped piercing punch is fitted it is left in the punch plate to act as an additional guide.

In making the piercing punches, they are attached to the punch holder and the holder plunger, the frame is assembled and babbitted, and the piercing punches are sheared while the plunger is guided by the babbitt bearing. The upper stripper, that works inside the blanking die, is blued on its face, and, removing the piercing punches from the plunger, the stripper is placed in the die, the plunger is replaced in the babbitt bearing, the stripper brought in contact with the blanking punch, and the outlines of the piercing dies are scribed on the face of the stripper. The stripper is then drilled out and filed to the lines. The punch plate containing the piercing punches may be tried from the back of the stripper, and the openings in the stripper filed until the piercing punches pass through to the face of the stripper without being forced.

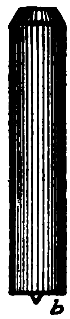


Fig. 20. Prick-punch

Placing Round Holes. For transferring any round hole not centrally located from the templet to the punch holder or to the die, a small prickpunch, Fig. 20, is turned up, one for each hole, and the prickpunch must fit the hole. At the same time that the body of the prickpunch is turned to fit the hole the small point *b* is turned. The prickpunches are hardened, and the templet is clamped or held to the punch plate by a few small drops of solder, the prickpunch is entered in the corresponding hole in the templet and lightly tapped

on the end with a hammer. After the centers of all holes have been prickpunched the punch plate is strapped to the lathe faceplate, the prickpunch mark indicated, as shown in Fig. 21, and the holes carefully spotted and drilled.

The holes should be bored if possible. It is not safe to trust a drill starting centrally in a carefully made spot. Neither is it safe to trust a reamer to size a hole, even if the hole has been bored nearly to size, for a dull tooth on the reamer, or a soft tooth, or a hard spot in the steel at the edge of the hole, or a burr may cause the reamer

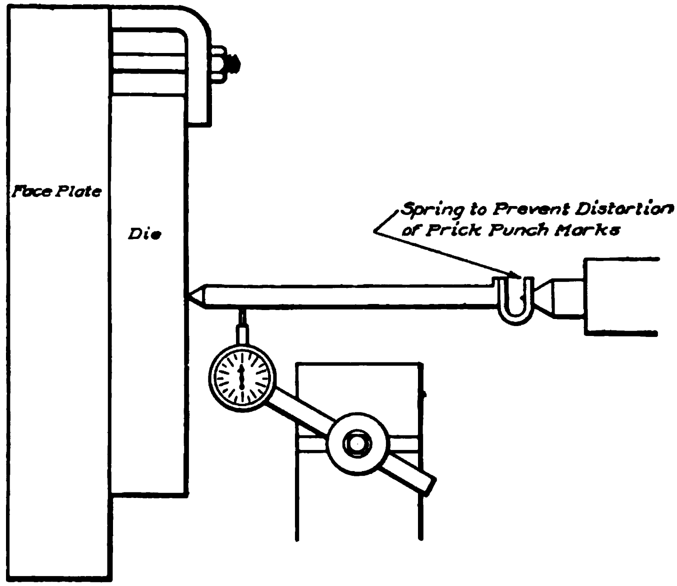


Fig. 21. Method of Locating and Indicating Prickpunch Mark

to deviate slightly. The only dependable method is to bore the hole with a single-pointed cutting tool—it does not matter whether the tool is stationary and the work revolves, or the tool revolves and the work is stationary.

Use of Master Plate. If the die being made is for a product that will be used year after year, or if the quantity of the product is such that new dies must be frequently made, it is good practice to make a master plate. This is done by machining a ½-inch plate of soft steel or cast iron perfectly parallel, and of the same size as the die, then, when making the die, the plate is fastened to the face of the

die and the holes are put in as above described or by the button method through the master plate and die, the holes in the master plate being bored one size.

When making the next die the master plate is attached to the back of the die, a soft-steel center in the lathe is turned to fit the hole in the master plate, the master plate to which the die is attached is wrung on this soft center, and the die is clamped to the faceplate, and spotted, drilled, and bored. As the soft center in the lathe was turned, it therefore is central with the lathe spindle, and, as the center fits the hole in the master plate, it is obvious that a hole drilled and bored in the die will be directly in line with the hole in the master plate. This is the most accurate method of transferring holes. Great care must be exercised when transferring holes from a templet or a master plate to have the proper side of the plate against the die. For instance, in transferring from a templet to a die, one face is against the die, but, when using the same templet to transfer to the punch plate, the opposite face of the templet must be against the punch plate. This is caused by the face of the punch plate being up when transferring the holes, but down when the punch plate is in use.

Assembling Parts. The blanking punch and die, and the crossbar punch *o*, Fig. 17, for the blanking punch, are hardened, the bar punch is inserted in the blanking punch, and both punches are screwed to the base. The piercing punch *R*, Fig. 17, which is evenly coated on the face with solder is attached to the punch holder and the punch holder is attached to the end of the plunger. The blanking die is attached to the plunger by screws and dowels, but a thin parallel washer, or ring, a trifle smaller in diameter than the outside diameter of the die and about $\frac{1}{32}$ inch thick is placed between the blanking die and the plunger to cause blanking die *j* to protrude $\frac{1}{32}$ inch beyond the face of punch *R* so that blanking punch *a* can be entered in the blanking die. The frame is now fastened to base, care being exercised that there is no grit between the bottom of the frame and the top of the base.

The plunger is placed inside the frame, and the punch and die entered. The frame cap *c*, Fig. 17, which fits the plunger is screwed on the end of the frame, which locates the plunger centrally in the frame. The entire mass is now inverted, and, resting the cap on

parallels the frame is slightly heated with a gas torch, and the molten babbitt is poured in the frame. Putty is used at the die end of the plunger to prevent the babbitt leaking. The whole mass is allowed to become thoroughly cooled before disturbing. When cool, the inside outline of the blanking punch is forced into the soft solder on the face of the piercing punch.

The plunger is now removed from the frame, piercing punch *R*, Fig. 17, is removed from the plunger, and slot *S* is milled or shaped to the line on the solder. After milling very close to the line the parts are reassembled and the punch is sheared far enough to obtain a good impression on the steel punch. The punch is now carefully milled or filed to remove all marks of shearing.

SECTIONAL DIES

Advantages. When dies are large or when there are many weak projections, it is good practice to make the dies in sections. One reason is that the individual pieces of a large die can be machined to shape easier. Another reason is that a long die or a large die would distort appreciably when being hardened, which would mean that the die could not be finished to exact size, but that a considerable amount of stock must be left on the large solid die in order to grind to shape after hardening. In the case of weak projections in a die, if the die is left solid and one point breaks, the entire die is ruined, whereas, with a sectional die, that part containing only the broken portion can be removed and a new one made at a small cost.

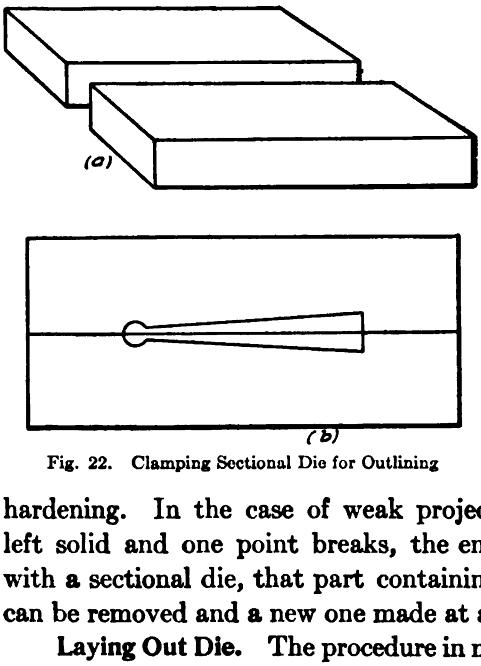


Fig. 22. Clamping Sectional Die for Outlining

Laying Out Die. The procedure in making such a sectional die as in Fig. 325, Tool-Making, Part III, would be to machine the two strips as in Fig. 22, herewith, and, clamping them together, to lay

out the outline from a templet or drawing in the same manner as the die in Fig. 4 was laid out.

Shaping of Die. The parting line of the two halves should come in the center of the scribed outline. The operation of drilling along the line as in the case of the die in Fig. 4, would be useless,

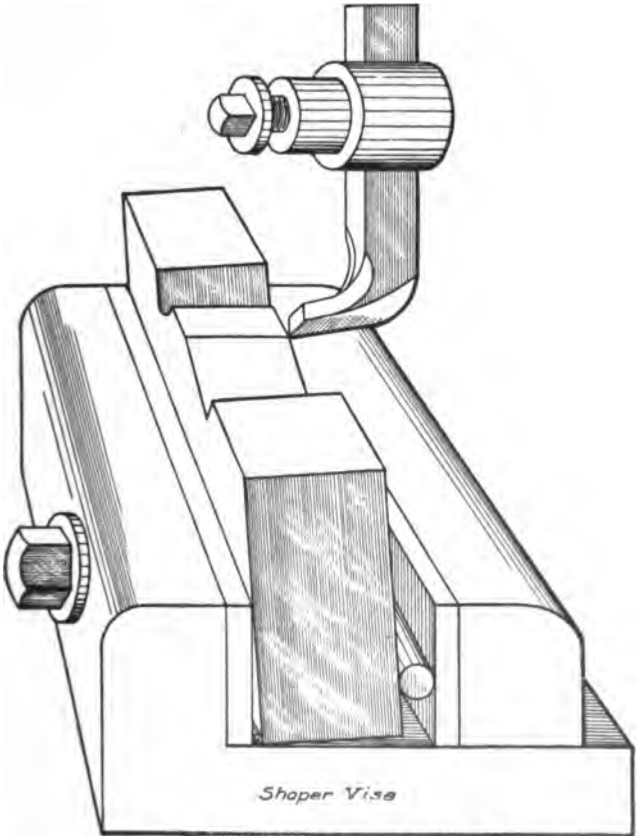


Fig. 23. Shaping Die, Showing Method of Obtaining Clearance

for the end hole can be drilled, and reamed tapering, then each half in turn may be gripped in a shaper vise, Fig. 23, and, by placing a small wire or a strip of folded paper of the right thickness to tilt the strip at the desired angle for clearance, then placing, say, a ½-inch rod at the mid height of the jaws, the opening in the strip

can be easily machined to size and the clearance can be machined at the same time.

Shearing Precautions. Several dowel holes are drilled in each strip, if possible, in addition to the screw holes for fastening to the die shoe, and, after hardening and grinding the die strips, the die shoe is machined to receive the two strips. A snug fit is necessary. The dowel holes are now transferred from the die strips to the die shoe, and the dowels are inserted. There is always more or less spring to a sectional die when shearing the punch. Care must be exercised in not attempting to shear too much stock, as the dies will spread.

Fig. 24 shows the method employed in making a small sectional die of simple design having weak projections. It is obvious that weak points, such as shown on this die, would not withstand the

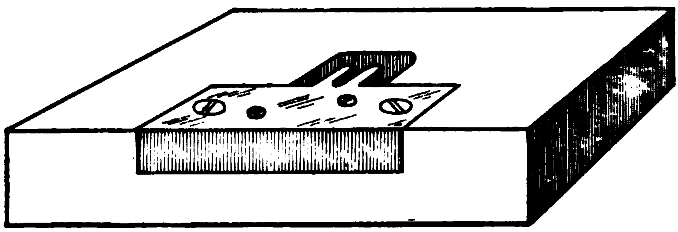


Fig. 24. Making Sectional Die with Weak Projections

pressure necessary to shear much stock. Therefore, when shearing a punch having such points, always remove the stock by scraping or filing and do not allow the points in the die to shear the punch. Great care also is necessary in withdrawing a punch from a die of this character when shearing the punch.

Hardened and Ground Sectional Type

Construction Requirements. The cores for coils and armatures are made up of variously shaped laminated soft-iron punchings, which, as a rule, must be extremely accurate. The iron sheets are rolled hot, producing a hard scale or oxide which causes severe wear on punches and dies. The dies must be frequently ground, as burrs on punchings are prohibited, and if the dies were given clearance each grinding would produce a larger punching. Therefore, due to intricate shapes that must be exact and the fact that the wear on

the dies is severe, the dies are invariably made of the sub-press construction and also made up of pieces, the latter being ground all over to size after hardening. There is no clearance given these dies and they are known as sectional or built-up dies.

Intricate Shapes. When the die is of extremely intricate shape, having a great number of pierced slots, Fig. 25, the usual method is to make a single punch and die, and, by the use of an accurate indexing fixture which holds the blank, the notches are pierced one at a time and the indexing done automatically by the stroke of the press. One operator can attend to several presses. The object in indexing and using a single piercing die is to eliminate the high cost of making a die to produce the blank in one stroke and also to eliminate the cost of repairs, for if one small point on such a die should break it would render the entire die useless until repaired.

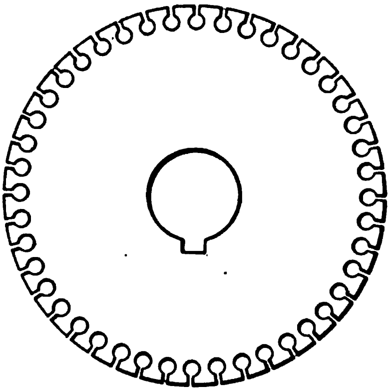


Fig. 25. Die with Pierced Slots

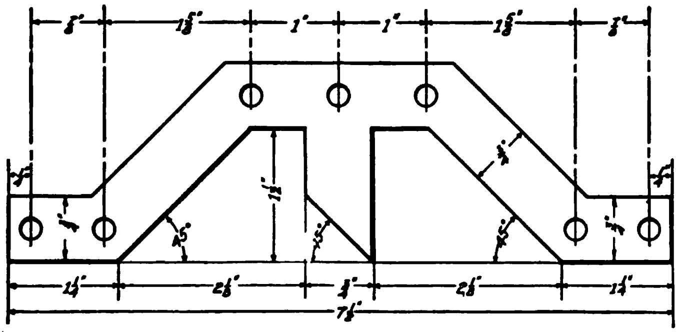


Fig. 26. Typical Punching with Dimensions

The punching shown in Fig. 26, while extremely accurate, is of a comparatively simple design, but the method of making is the same as for dies for more intricate shapes. The punchings are built up as in Fig. 27, and every other one is reversed, so that the error must be slight, for in reversing the blanks the error is doubled.

Making of Die. *Division in Pieces.* When laying out a built-up die that is to be ground to shape and size after hardening, the

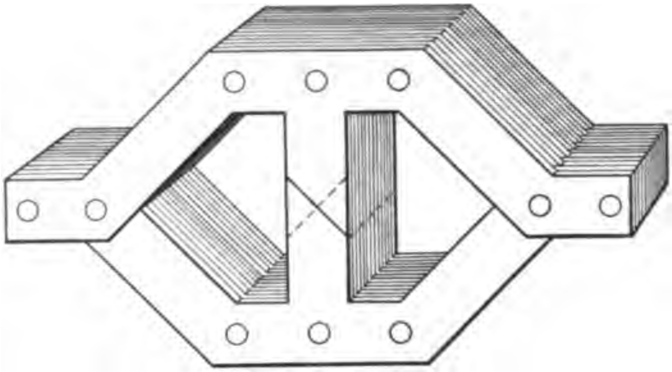


Fig. 27. Method of Mounting Punchings Shown in Fig. 26

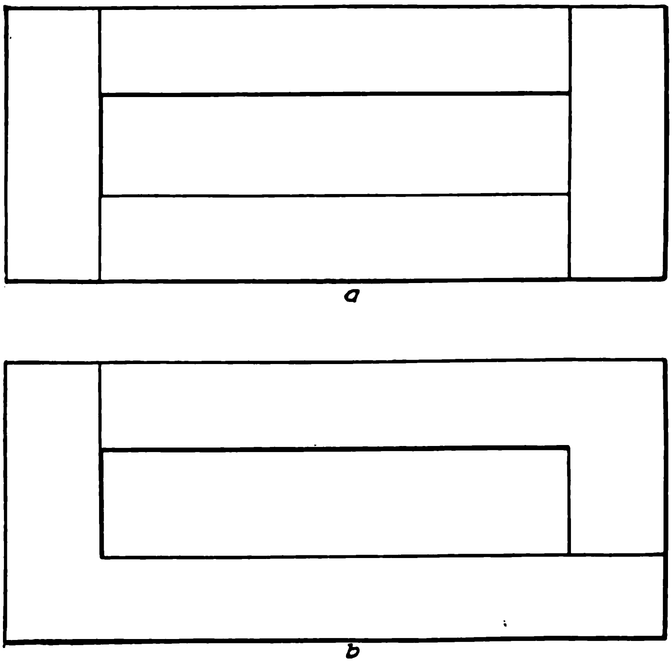


Fig. 28. Two Methods of Making Sectional Die

sections should be as free from internal corners as possible, as it is a difficult job to grind a good sharp inside corner. For instance, referring to Fig. 28, it would be easier to make and grind the four

pieces, as at *a*, than it would be the two pieces with inside corners, as at *b*. Therefore, the division of the die at hand for sections requires considerable study.

Referring to Fig. 29, it will be seen that the division lines are so placed that there are no corners in any one piece and that each piece is comparatively easy to make. Instead of laying out from a templet, or roughing out the pieces and placing them in position, then laying out the outline on the pieces, a better way is to make

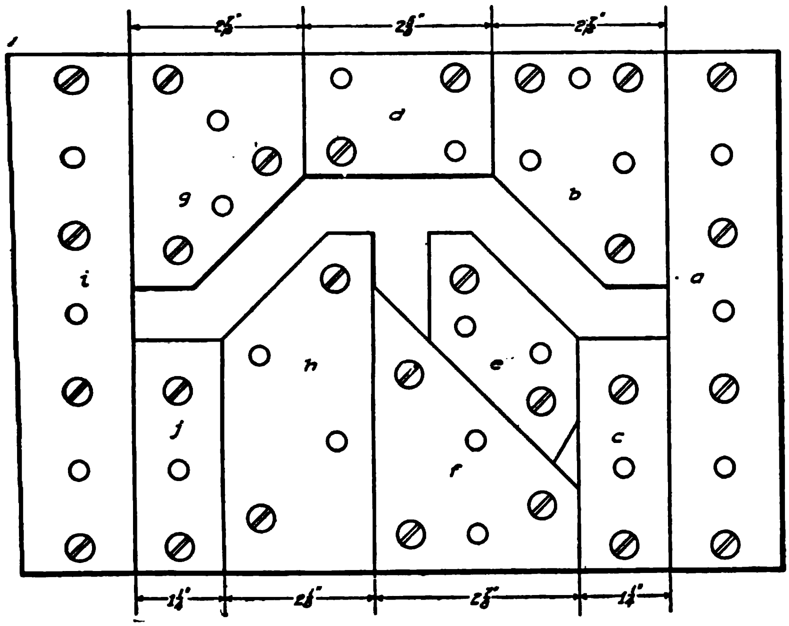


Fig. 29. Building Up Die for Punching Shown in Fig. 26

each piece by measurement. The pieces *a* and *i* are simple end pieces, perfectly straight, and can be eliminated from the description of making. Referring to piece *b*, Fig. 29, we find by totaling the dimensions on the drawing, Fig. 26, that the piece is 2 $\frac{7}{16}$ inches wide and that the angle is 45 degrees. This piece is carefully planed or milled to exact shape, but, say, .010 inch is left on each surface for grinding. Piece *c*, Fig. 29, is important, as the width governs the length of the end of the punching. Referring to the drawing, Fig. 26, we find this width to be 1¼ inches, and .010 inch is left on each surface for grinding; and so on, until all pieces are

roughed out to within grinding allowance. The edges and bottom of all pieces must be at right angles even when in rough size.

Doweling Hardened Pieces. After all pieces are roughed out the screw and dowel holes are drilled. The dowel holes, however, are drilled, and then tapped with a fine-pitch thread; if a $\frac{3}{8}$-inch dowel is used, the holes can be tapped, say, $\frac{1}{2}$—32 pitch. The object of tapping the dowel holes is to permit screwing in tight-fitting soft-steel plugs after the pieces have been hardened, following which the plugs are dressed off flush with the top and bottom of the piece. Then after all pieces are ground to size and securely fastened in proper place by means of the screws, the dowel holes are drilled and reamed through the soft-steel bushings or plugs and into the die shoe. This is better practice than to drill and ream the dowel holes in the pieces before hardening, for, after hardening the pieces, the holes are slightly distorted; but, granting that the holes remained true, it becomes necessary to transfer the holes to the die shoe, and in order to do this a drill is used, using the dowel holes in the hardened pieces as a jig. The drill used must of necessity be somewhat smaller than the hole in the hardened piece, possibly not more than one or two thousandths, but whatever the difference between the drill and the hole is, that difference can cause an error in the alignment of holes in the hardened piece and in the die shoe, as the drill can bear against one side of the guide hole, drilling the hole off center. Using the hardened pieces for a guide prohibits the use of a reamer, for, in order to have the reamer size the hole in the die shoe and to bring the hole in the die shoe absolutely in line with the hole in the piece, the reamer must fit the hole in the hardened piece, which of course would ruin the reamer. The greatest objection to using the holes in the hardened piece for a guide for the drill and reamer is that the holes are invariably distorted during the hardening process.

Having drilled and deeply counterbored all screw holes, and drilled and tapped all dowel holes, the pieces are hardened, but, as the die is to cut iron having scale, the die is left harder than for ordinary sheet steel.

Grinding Pieces. The first grinding operation is to take a chip across a temporary bed, or the grinder bed itself, or the face of a magnetic chuck to insure the surface being parallel with the travel

of the cross-slide and the travel of the bed. The pieces are examined on the bottom side to make sure no burrs are protruding or scale adhering to the pieces that would tilt them, for there is only an allowance of .010 inch to remove, and a slight tilt might be sufficient to prevent the pieces cleaning up all over. All pieces are then placed on the newly finished bed and waxed to the bed, unless a magnetic chuck is employed. After all pieces are ground on the top side, the wax is thoroughly removed from the bed, the pieces cleaned, and the surfaces just ground are waxed to the bed, and the bottoms then ground. All pieces now are of uniform thickness and parallel.

An angle iron, or, what is better suited for this class of work, a hollow square, absolutely square in every position, Fig. 30, is now

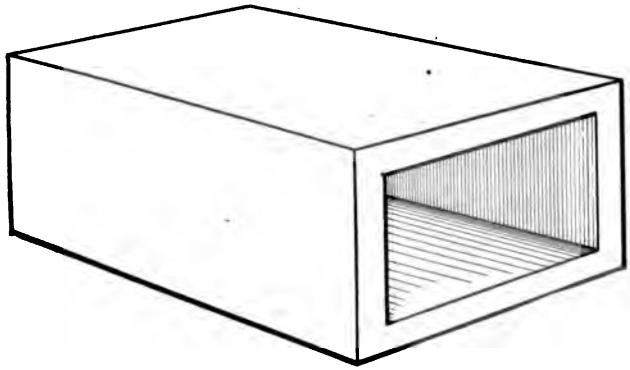


Fig. 30. Hollow Square Used for Holding Pieces for Grinding

waxed to the surface of the newly machined bed. In either case the angle or hollow square must be absolutely square and must be waxed to the bed so that the vertical face of the angle is absolutely parallel to the line of travel of the bed. This is accomplished by clamping an indicator to the side of the wheel. Do not trust a square against the machined surface of the uprights of any machine, if the surface of the work must be parallel with the line of bed travel, for by so doing we are trusting to the accuracy employed by the machinist who built the machine: eliminate all chance.

Assuming that the hollow square is correctly located and waxed to the bed, the first piece to be ground can be *a*, Fig. 29. By clamping the piece to the hollow square and using the indicator attached to a surface gage, the piece can be positioned parallel with the surface

of the bed by testing each end of the piece for height, using the indicator. The piece need project above the hollow square only a slight distance, say $\frac{1}{16}$ inch. As the top and bottom of piece *a* are perfectly parallel and the hollow square is perfectly square—at right angles—it is obvious that when the upper face of piece *a* is ground, the face will be at right angles with the top or bottom.

Piece *b*, Fig. 29, is clamped to the hollow square, as in Fig. 31, and the end of the piece is lined up with the bed by placing a square on the bed. The use of a square will be found accurate enough for the grinding of the first edge, but, after one edge is ground, if the remaining edges are trued up at right angles with each other by holding the base of a square against the vertical edge of the work, and using an indicator clamped to the emery wheel and with pointer

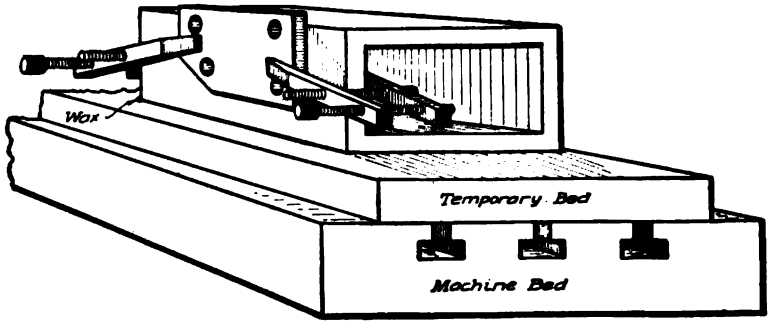


Fig. 31. Piece Clamped to Hollow Square on Machine Bed

sliding along the blade of the square, as in Fig. 32, the work can be made more accurate than by holding the blade against the work while the base of the square is on the bed of the machine. After the first edge has been ground, the piece should be tested, as in Fig. 33, to prove that the side of the hollow square is at right angles with the bed, as grit can get under the hollow square unless extreme care is exercised. The piece *b* now being ground on two sides, its succeeding sides or edges may be ground by a similar procedure.

Each piece must be ground on the edges as above described, always using the indicator to square up the work, for the use of parallels is not safe. A slight nick on a parallel or a piece of grit or even a slight taper of the parallels would of course be transferred to the work.

Placing Die Pieces on Shoe. After all pieces have been ground to exact dimensions, they are attached to the die shoe and placed in position by soft test pieces that have been machined the right thickness. These test pieces are placed in the opening of the die, and the die pieces are brought to bear against the test piece, in which position the hardened pieces are securely fastened in place by

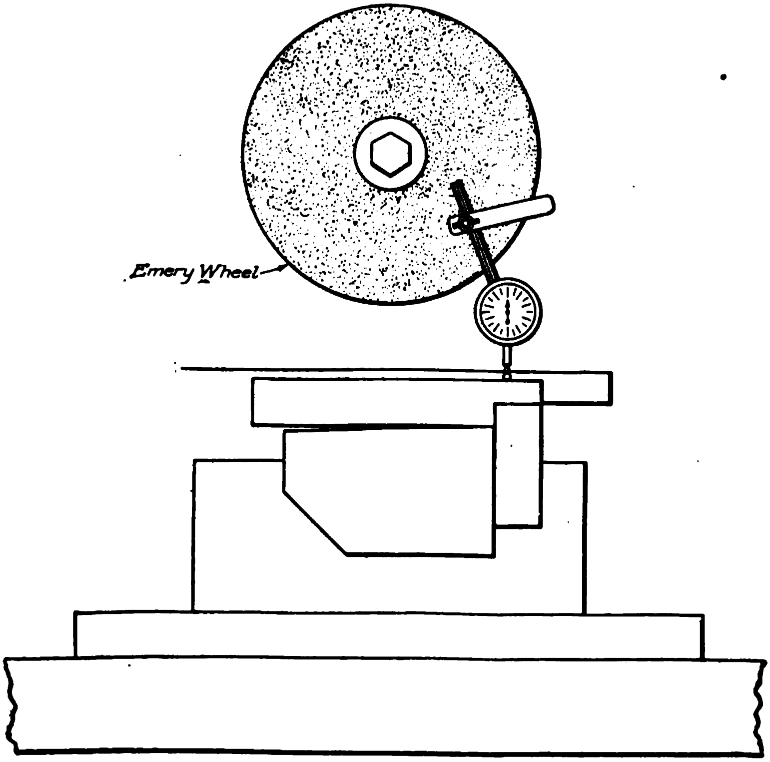


Fig. 32. Emery Wheel and Indicator Mounted for Grinding

screws. After tightening the screws the die should be gone over again to see if some piece had moved a trifle when tightening the screws; then drill and ream for dowels.

Attaching Piercing Punches. While the die pieces are attached to the die shoe, the die shoe is in turn attached to the punch holder, as the die in all sub-press construction where piercing punches are employed in conjunction with blanking operates as the upper member. It will be noted that the piercing punches for the holes shown

in Fig. 26 have not been inserted in the die as yet, for the reason that it is easier to put the piercing punches in place after the die is complete. This is accomplished by drilling holes in the die shoe approximately where the punches will come but by making the holes a trifle larger than the larger diameter of the punch and then inserting the piercing punches in small individual punch holders, these punch holders in turn being attached to the back of the die shoe, the punches can be properly located from the holes in the blanking punch by shifting the individual holders one way or another and may be securely screwed to the die shoe when the punches are in proper location. The individual punch holders can be inserted in recesses in the die shoe, or can be screwed on top of the die shoe, and the punch holder recessed to clear them. The locating of punches in this manner eliminates considerable boring of a very accurate nature. Another method of inserting the piercing punches in the upper half is to complete the blanking punch, then the die, and, by entering the punch in the die, the holes in the blanking punch which are the piercing dies can be transferred to the die shoe. This is not as accurate, however, as the adjustable punch-holder method.

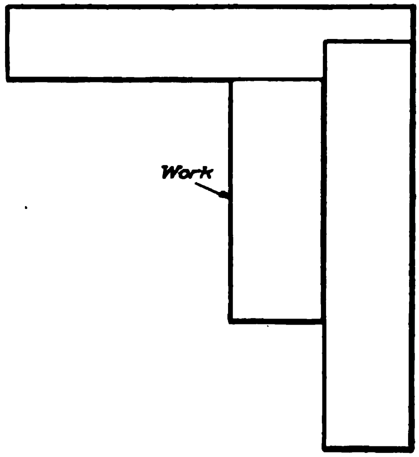


Fig. 33. Proving Accuracy of Work after First Edge Is Ground

Making Blanking Punch. The blanking punch is also made up of pieces and is more difficult to make than the die, for the holes in the blanking punch which are the piercing dies must be very accurately located and bored, and, after hardening the punch pieces, the punch pieces are ground to shape and dimensions from the holes.

Measuring from Piercing Holes. The holes are put in the soft pieces of the punch after the pieces have been roughed out to within the grinding allowance. After hardening, the holes are thoroughly cleaned, and taper plugs are turned of soft steel to fit the tapered holes. That portion of the plugs, however, that extends beyond

the face of the punch, Fig. 34, is straight and all diameters must be exactly alike. When grinding the punch sections, the plugs rest on the hollow square or on the top of the angle iron to insure the edge being ground parallel with the hole, and the method of measuring for proper thickness is as shown in Fig. 34. The small projecting plugs must be of exactly the same diameter, but the actual diameter is immaterial. The punch thickness is ¾ inch, and, assuming that the projecting ends of the plugs in the holes are .250 inch in

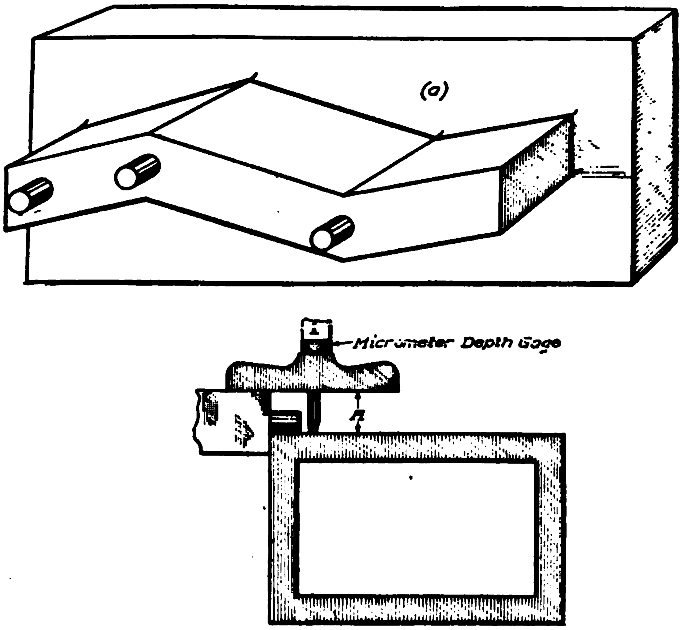


Fig. 34. Measuring Thickness of Piece with Depth Gage

diameter, it means in this instance that the distance A must be one-half the thickness of the punch plus one-half the diameter of a plug or $.375+.125=.500$ inch.

Discrepancies. When a portion of a punch is at an angle, the grinding of the punch sections requires considerable care and skill due to the fact that discrepancies on abutting ends of punch sections will greatly multiply themselves at the extreme ends of the punch as in Fig. 35. A slight opening as at *a*, Fig. 35, is permissible.

The object in making the punch thin, then attaching it by screws to the soft-steel punch block *a*, Fig. 34, is for rigidity. It

would be easier to make the punch as in Fig. 36, leaving enough stock to grind to size, then grinding out the holes to proper location, but the face of the punch that bears against the holder is too narrow

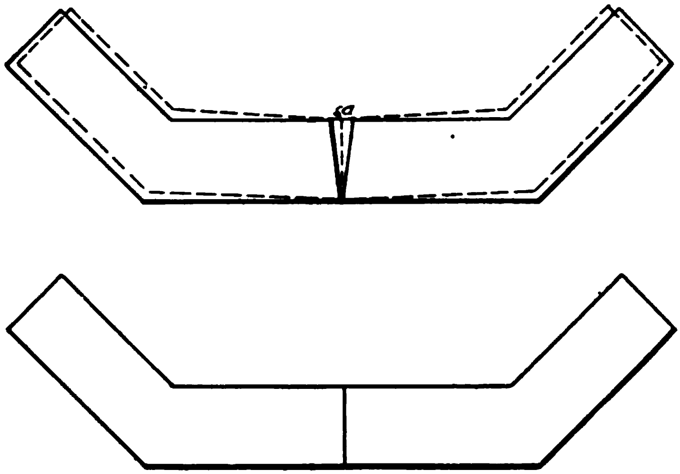


Fig. 35. Sectional Blanking Punch, Showing Exaggerated Opening for Making Adjustments and Completed Sections

for a working seat, and any miscut by the press operator, or a piece of scrap punching adhering to the sheet being punched, would

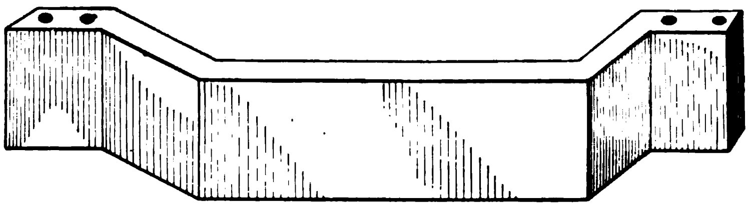


Fig. 36. Punch Easier to Build than Fig. 35 but Not So Satisfactory

cause the punch to spring to one side. This causes the edge of the punch to strike the edge of the die, and a broken member or a sheared punch is the result.

GANG DIES

Accuracy Required in Making. By referring to Fig. 341, Tool-Making, Part III, it will be noted that in addition to the blanking punch there are two piercing punches attached to the same holder. Since these piercing punches, as well as the blanking punch, must

be in perfect alignment with the dies, the method of procedure is different from that in connection with the simpler dies, and a gang die requires careful laying out. Assuming that the die we are about to make is the shape and type shown in the illustration referred to, we will first consider the different methods which could be employed to make the die, and then select the most practical one.

Drilling and Filing Method Precluded. A true radius is shown at each end of the blanking die *E*. If we were to drill holes just inside the lines and to broach out the center piece as described for the die of Fig. 4, difficulty would be experienced in filing the ends, as it is extremely difficult to file a true radius. Besides, this method would entail considerable hand work, and it is good practice to eliminate hand work as far as possible. The drawing, Fig. 37, calls for a positive distance between the two piercing dies, and also calls for a blank 2.250 inches long. It is shop practice that, when dimensions are given in thousandths of an inch, the dimension is important and must be adhered to within a thousandth. When given in four decimals, finer accuracy is required, but when given in fractions, a variation of several thousandths is permissible. Therefore, the length of the blank being important, and the ends of the blank being of a true radius, the drilling and filing method is precluded.

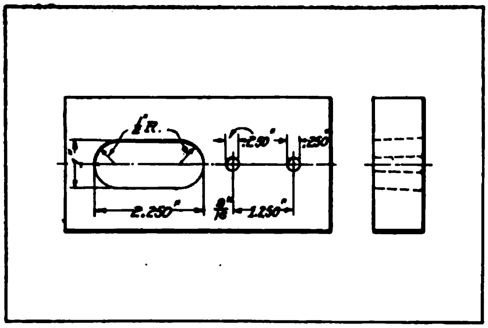


Fig. 37. Drawing for Gang Die Blank

Errors of Drilling and Counterboring Method. The location of the holes and blanking die could be laid out with a height gage, and, where the lines cross, fine prickpunch marks should be placed, from which as starting points the holes could be drilled and counterbored to proper depth for bushings or counterbored clear through for the piercing die proper. But there are several chances for errors in this method: (1) The prickpunch mark may not be placed exactly at the intersection of the lines. (2) The drill may not have started exactly in the center of the prickpunch mark, or granting that it

did, the drill can *run*, which is the shop term applied to a drill leaving its intended travel or path. (3) The holes must be given clearance, and, since they are drilled, the taper reamer is the logical method. We have already shown how a taper reamer will start on an angle carrying the center distance of holes one way or another. (4) When drilling and counterboring the two end holes to form the radial ends of the blanking punch, the prickpunch can be out, the drill can start wrong, and the pilot of the counterbore in not fitting the hole can change the center distance and the counterbore may cut too large even though it measures the proper diameter. (5) The final opportunity for error is in the reaming of holes for clearance. All these chances for errors must be considered, and here again is where a careful study of the drawing would show that the ordinary easy method cannot be used.

Approved Method of Making. The proper sequence of operations to make this particular die would start with planing up the die block, stripper, and punch plate.

Placing Holes. If the piercing punches *BB* in Fig. 341, Tool-Making, Part III, were, say, 1 inch in diameter, it is obvious that the punch holes in the punch plate and the die holes in the die must be exactly in line, as a large punch will not spring into the die as is the case with punches of small diameter. Therefore, the best way to make these holes in line would be to dowel the stripper to the die face and dowel the punch plate to the stripper, then lay out the holes by means of a height gage, and indicate the center mark on the punch plate true by clamping the die block containing the stripper and the punch plate to the faceplate of a lathe. Then spot the punch plate with a V-spotting tool held in the tool post, and drill, and bore the punch plate and stripper to the desired diameters. Remove the punch plate and stripper and bore the larger recess in the die for bushing. The die must be clamped to the faceplate in such a manner that the punch plate and stripper can be removed without disturbing the location of the die on the faceplate. Very accurate results can be obtained in this manner, providing the holes are bored after drilling.

A more accurate method of locating the holes is to attach the punch plate and stripper to the die, then lay out approximately the location of the holes on the rear side of the punch plate. A small

hole is drilled and tapped say for a No. 10—32 screw in the center of the approximate location for the holes. Buttons that are faced on one end at right angles with their sides and that have a hole, say,

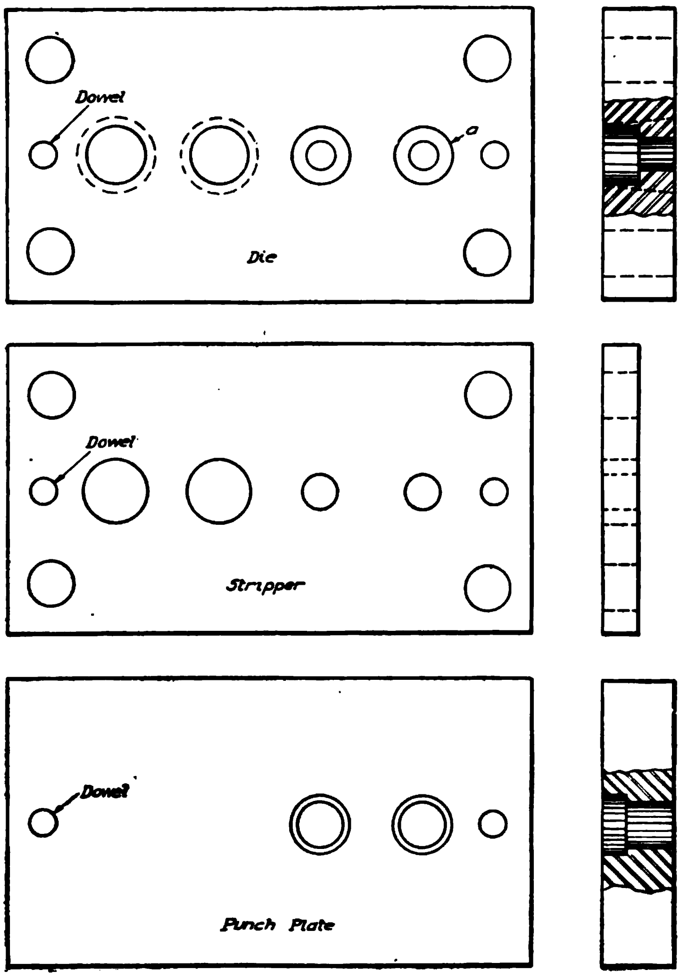


Fig. 38. Diagrams Showing the Die, Stripper, and Punch Plate

$\frac{1}{8}$ inch larger than a No. 10 screw are now attached to the punch plate, as fully described in Tool-Making, Part II, Figs. 268 and 269. The object in using the button method is that the die-maker is enabled to measure with micrometers from outside to outside of buttons and can place the buttons to within a tenth of a thousandth.

When the die is removed from the lathe faceplate, the die, stripper, and punch plate are in the condition shown in Fig. 38. The piercing dies are recessed as at *a* on the die block in Fig. 38, for the reason that the diameter of the hole is given in thousandths, and should the holes be bored a trifle too large, the die would be practically ruined, otherwise. Also, it may be desired to change the diameter of the piercing dies, which can be readily accomplished by removing the bushings and inserting new ones having holes of the desired diameter.

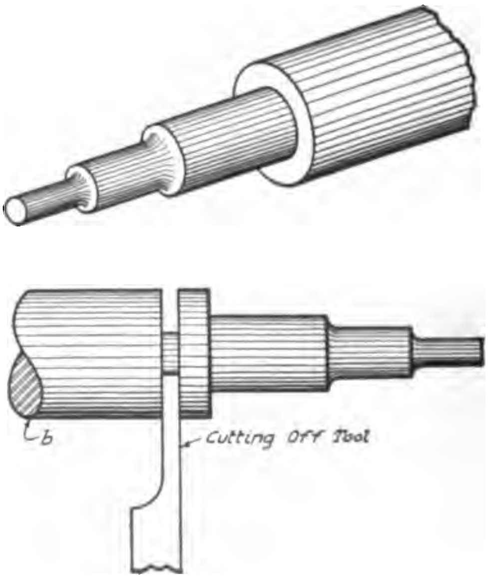


Fig. 39. Making Punches for Gang Dies

Referring to Fig. 38, it will be noted that the clearance had been bored in the ends of the blanking die. All that remains to complete this die is to carefully mill out the web between the two holes; or the web may be cut out using a hack saw, and the sides machined in a shaper which will insure good straight lines. The same precautions relative to screw holes and hardening as already described must be followed out on all dies. The stripper is machined out in the same manner.

Punches. The punch plate is set on the die, care being exercised that the proper side is placed against the die and that the punch holes line up approximately with the die holes. The outline of the die is now scribed on the punch holder in order to find the approximate location of the blanking punch. The blanking punch is preferably turned with a shank, and a hole is drilled and reamed through the punch plate for a tight fit on the punch shank.

The piercing punches must be made, hardened, and ground, if necessary, and inserted in the punch plate before the blanking

punch is made, for the piercing punches, being left somewhat longer than the blanking punch, are used as guides to positively locate the blanking punch over the blanking die. If the punches are to be ground, they can be turned upon centers, or can be made as in Fig. 39, and the piece that is held in the chuck is left on the punch and serves as a holding means when grinding. After the punches are ground, the soft end can be cut off as at *b*, Fig. 39. Punches made with a head are easier to make without centers, and, as the

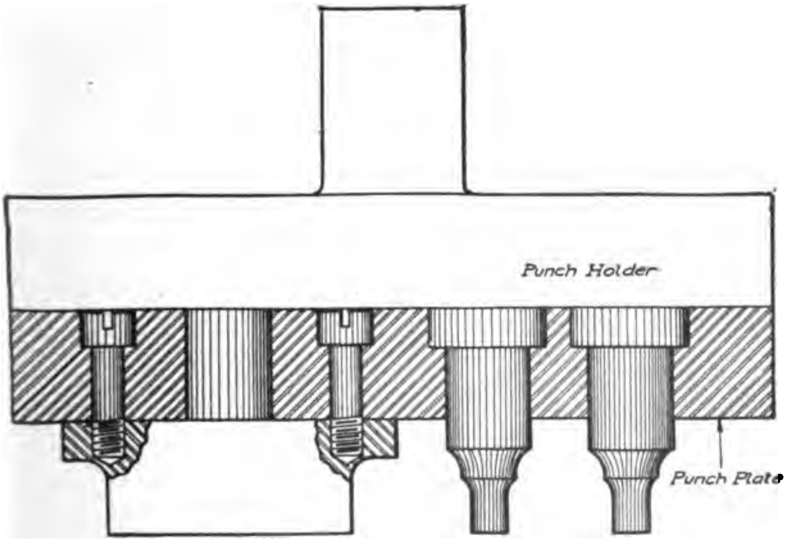


Fig. 40. Method of Holding Punches and Blanking Dies

punch plate is attached to the punch holder as in Fig. 40, the punches cannot push out or pull out.

Having inserted the piercing punches and the blanking punch in the punch plate, a dowel hole is now drilled and reamed lengthwise of the shank, as in Fig. 41. The hole should be drilled so that three-fourths of the diameter of the dowel pin is in the punch plate. A well fitting dowel pin is driven in this hole and the punch is ready to lay out. Upon entering the piercing punches in the piercing dies the face of the blanking punch comes in contact with the face of the die, in which position the outline of the die is scribed on the face of the punch. The blanking punch is now driven from the punch plate and milled to the line, beveled, and returned to the punch

plate to start the first shear, being guided by the piercing punches which, being longer, of course enter before the blanking punch comes in contact with the plate. After the blanking punch has been forced in a short distance, the punch may be removed, or may be finished while in the punch plate, as suits the fancy.

Pilot pins to enter the holes pierced in stock must be placed in the blanking punch and must be exactly the same center distance apart as the piercing dies, or else the holes will be distorted when blanking. In this particular die a thin disc 1 inch in diameter may be turned on the end of a rod held in a lathe chuck, and, at the same setting to insure concentricity, a hole drilled and bored to fit a standard drill. The disc is then severed from the bar and may be clamped to the face of the punch so that the edge of the disc is exactly in line, or even, with the end of the blanking punch. The drill, since it fits the hole, drills the holes very close to the exact distance from the ends and the side of the punch. These pilot holes must be drilled clear through the punch, as the pilots are driven out when grinding the punch. The pilots are made with a shoulder and tempered to a dark blue, and, when the punch and plate are assembled, they appear as in Fig. 42.

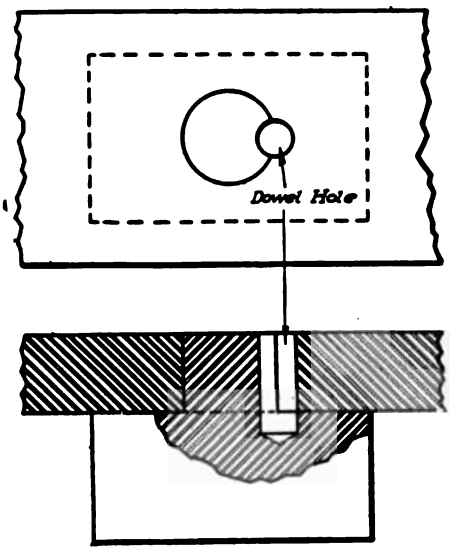


Fig. 41. Method of Drilling Dowel Hole

Proper Sequence. The reason that the piercing punches are made and inserted first is that the piercing-punch holes were already in the punch plate, and, if the blanking punch were fitted to the die without the piercing punches being entered in the die, the piercing punches would not line up with the die. Whether the punch plate is bored at same time as the die, or not, the piercing-punch holes should be the first to be bored, and the punches should be used as guides. It is readily seen that to transfer the holes from the die to

the punch plate while the blanking punch is entered in the die means that the punch plate is some distance from the die, and to transfer the piercing holes would mean that the punch plate would have to be parallel with the die and that any transfer drill used would only be guided by a thin edge of the tapered piercing die—altogether making an unsatisfactory and unworkmanlike method, although this haphazard method is practiced by many so-called expert die-makers. When punches are located in this manner, it always happens that the punches do not quite line up and must be sprung over, if slender,

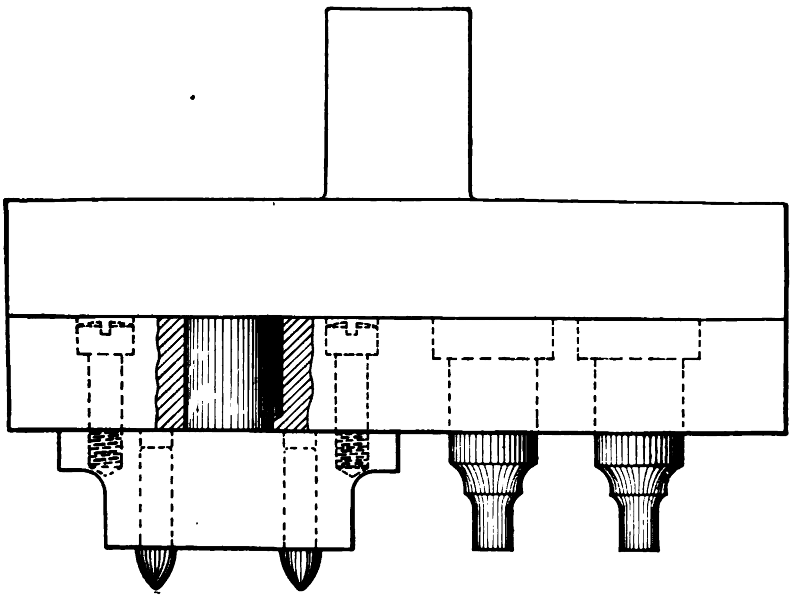


Fig. 42. Piercing and Blanking Punch Complete

and if too large in diameter to spring, the punch-plate stock surrounding the punch is swaged in order to crowd the punch over. Always use that method which contains the least number of chances for error, for, besides distinguishing the expert, it saves time in the end.

SHEARING DIES

Two-Punch Principle. The cutting action of dies termed shearing dies is similar to the action of shears, from whence they derive the name. When in use one part is placed in the punch holder and is called the punch, while the other half is attached to the die shoe

and is called the die, although in reality both members are punches. Shearing dies in their simplest form are used to cut pieces from

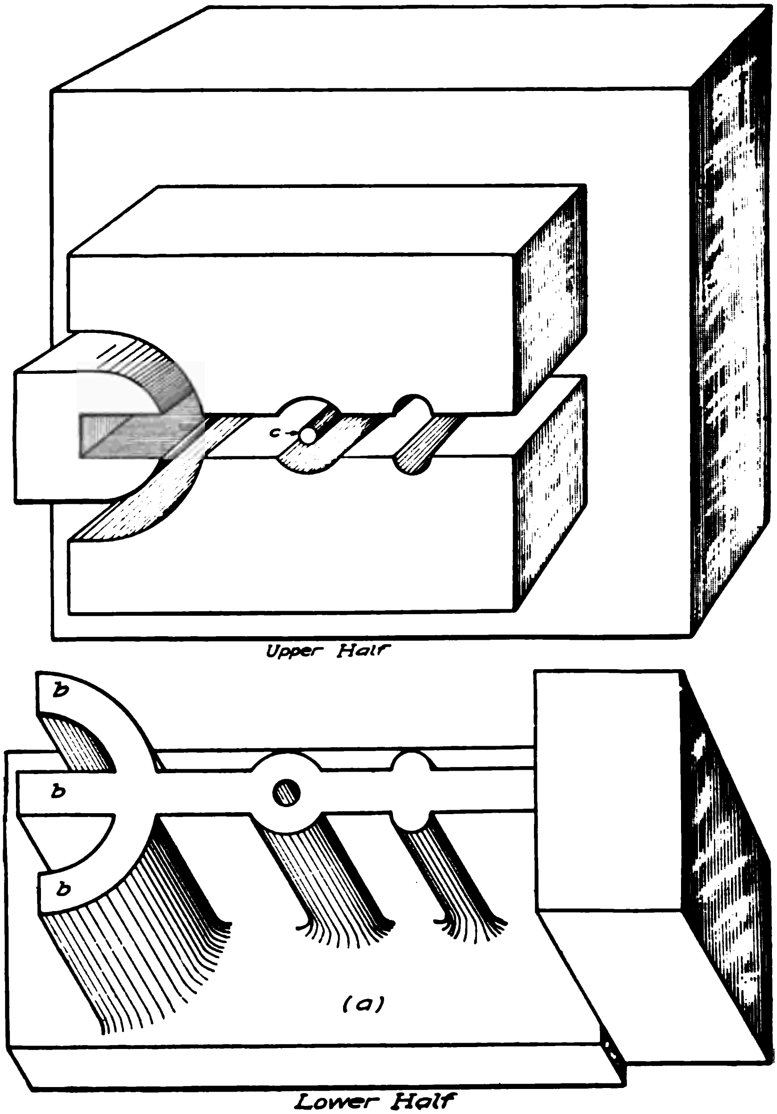


Fig. 43. Punch and Die Which Cut the Stock Away Leaving Blank Temporarily on the Strip

strips or bars, but the shearing or two-blade principle has been so elaborated upon that the most economical type of die is that employing the two-punch principle.

Advantages. Fig. 43 shows a plain type of die employing the two-punch method, and it will be noted that the method of obtaining the blank is directly opposite to that when a punch and die is used. An ordinary punch and die cuts the blank from the strip, while the type shown in Fig. 43 cuts the stock away, leaving the blank temporarily on the strip. This has many advantages. The blank can

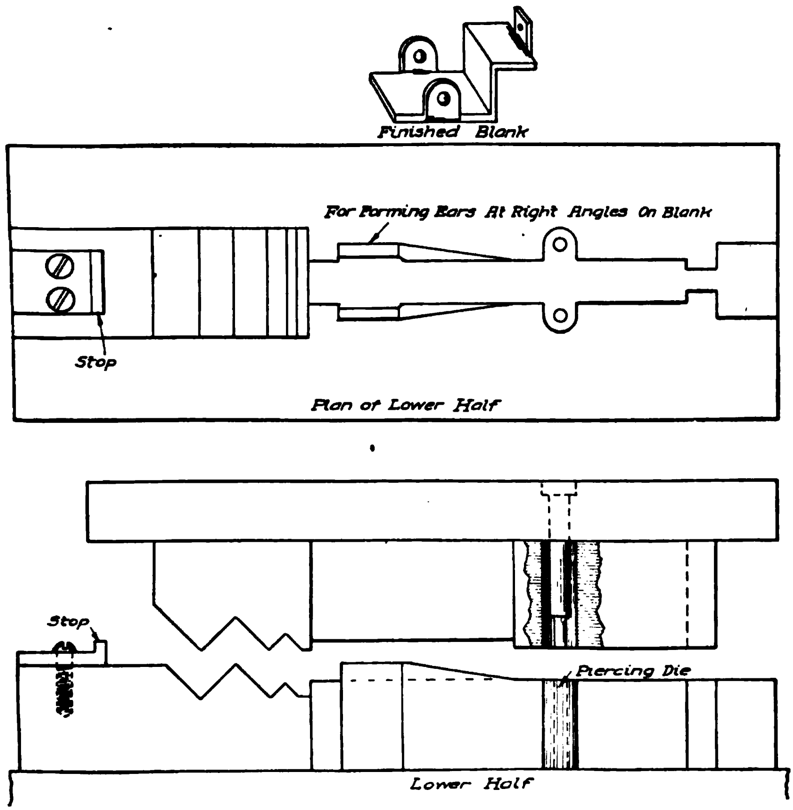


Fig. 44. Two-Punch Die with Formed Ears on Finished Blank

be put through a number of bending, drawing, or forming operations, and when finally completed the blank is severed from the strip by the shearing punch. This type of die also saves considerable stock, as the margin on the edge and the web necessary between the blanks when using a blanking die is eliminated. Fig. 44 shows a side view of the same type, elaborated upon to the extent of forming several ears before severing the finished blank.

Making Lower Punch. *Strains.* The first piece of the die in Fig. 43 to be made is lower punch *a*. It will be noted that the punch is not machined the same shape its entire height but that a supporting plate is left on the bottom. This plate or shoulder should be left on all punches that have long ears as *bbb*, for, without the plate, the ears would spread apart or spring together during the hardening process.

Another precaution that should be taken when making either a blanking die or a punch having long slender ears, as in Fig. 43, is to machine the steel all over to remove the scale, then slowly heat to bright red, and pack in lime to insure slow cooling and also to prevent

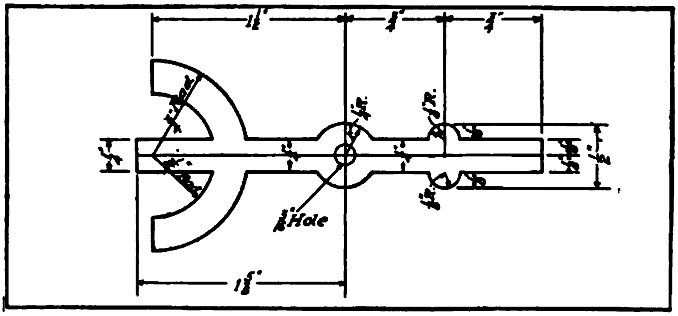


Fig. 45. Sketch of Lower Punch of Die Shown in Fig. 43

oxidation to a great extent. The object of annealing is to remove the strains in the steel.

Laying Out. Having machined all over and blued the surface of the block for the punch, center lines are scribed lengthwise or crosswise of the punch block. Referring to sketch Fig. 45, the first dimension at the right of the cross-center line is $\frac{3}{4}$ inch, therefore, a cross-line is scribed $\frac{3}{4}$ inch from the center line by means of either the height gage or surface gage, or by measuring with a scale and sliding a square along the block until the blade touches the scale. The block should now look as at *a* in Fig. 46. The next dimension to the right of this line is also $\frac{3}{4}$ inch, so the operation is duplicated, and the die block looks as at *b* in Fig. 46. Starting at the cross-center line the shortest dimension at the left is $1\frac{1}{2}$ inches, *c*, Fig. 46, and when this line is scribed on the punch the $1\frac{5}{8}$ dimension line *d*, Fig. 46, also is scribed crosswise. Before going further, each space

between cross-lines is carefully measured and checked with the dimensions on the sketch. The radius around the center hole calls for $\frac{1}{4}$ inch. Setting divider points $\frac{1}{4}$ inch apart, the circle is scribed as at *e*, Fig. 46. The large radius calls for $\frac{3}{4}$ inch, and is struck from a point $1\frac{5}{8}$ inches from the center and on the center line. As we already have this location, the divider points are set $\frac{3}{4}$ inch apart and a circle is scribed as at *f*, and from the same point the $\frac{1}{2}$-inch radius is scribed. Also from the same point there is scribed a $\frac{1}{4}$-inch

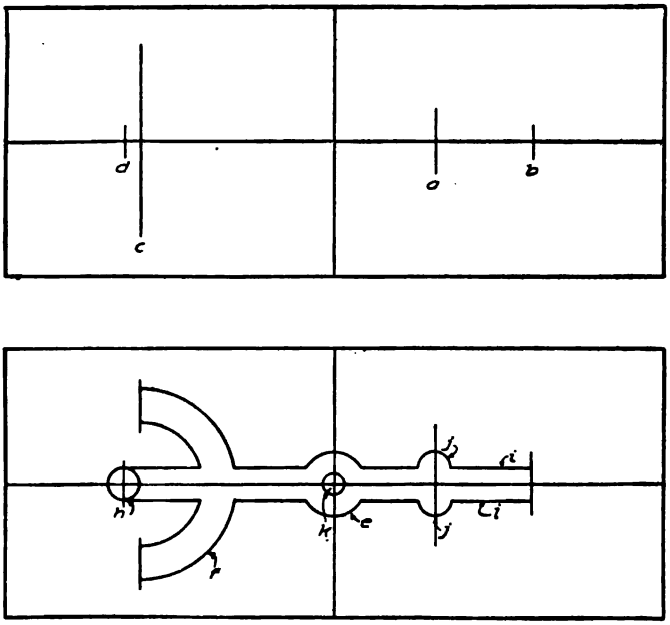


Fig. 46. Layout of Punch on the Block

circle *h* which is the width of the bar. Using a surface gage or a height gage the two lines *ii* are drawn on the punch block. The two $\frac{1}{8}$-inch radii *jj* are now scribed, completing the outline of punch. The $\frac{3}{16}$-inch circle *k* for the hole is scribed, and the punch is ready to machine.

Piercing Die. A small prickpunch mark should be made in the center of the circle for the hole, and a small drill, say a No. 50, that is well sharpened and which runs true when gripped in the drill-press chuck is first used to drill a hole say $\frac{1}{4}$ inch deep. The object in

using the small drill is that the tendency to climb out of the prick-punch mark is reduced to the minimum, then, when using a larger drill to size the hole, the point of the large drill is more apt to follow the small hole.

To indicate a hole in a job of this character would be a false attempt at accuracy due to the fact that the outside of the punch will be machined to a line. If, however, the dimensions are in thousandths, then the hole should be indicated and bored, and the ½-inch outside diameter *e* could be machined at the same setting while the punch is strapped to the faceplate of the lathe. To complete the outside diameter *e* in the lathe, however, would require a splining tool and that light chips be taken by sliding the carriage of the lathe back and forth.

The sides of the lower half must be straight, for the lower half is used to shear the upper punch parts.

Hardening. In hardening the lower part it should be placed in the furnace face down, and when dipped in the bath the face should be the first to enter and a slight up-and-down motion should be kept up until the punch is hardened. The base or flange should not be hardened. The object of keeping the punch in motion while in the bath is to prevent a crack or bulge which would take place if the punch were placed in the bath and held at one point. Where the water line comes on the punch there will invariably be a crack. A better way to heat a punch of this character is to heat it by immersing in a bath of red-hot lead.

Surfacing. After hardening, the face of the punch should be ground to insure a good sharp cutting edge all around, which is an aid when transferring the outline to the upper half. The back of the punch is now ground parallel with the face of the punch. This should be done by placing the face directly on the bed of a surface grinder and holding the punch to the bed with wax applied with a heated soldering iron. A suitable wax for this purpose consists of the following parts by weight: beeswax 7; resin 2; shoemaker's wax 1. It is obvious that, when two surfaces are to be parallel, great chances for errors are experienced in gripping the work in a vise, and, after machining one surface, in gripping the work again for machining the opposite side. Always work from one face to another when possible, and, if the work requires extreme accuracy

as regards parallelism, a cast-iron plate or a piece of steel somewhat larger than the piece of work to be machined is waxed to the bed of the grinder or shaper and the surface made smooth and true by light cuts.

We now have a temporary bed that is absolutely parallel with the line of travel of the shaper ram or the V-ways of the grinder. The piece of work is now in turn waxed to this temporary bed and one side of the work machined and all wax removed from the work and the face of the temporary bed, then the work is placed machined face down on the temporary bed, and the other side is machined. This temporary bed can be also applied to lathe work by strapping it to the faceplate of the lathe, and truing the surface as a temporary faceplate; then strapping the work to this temporary plate the surfaces can be properly machined.

A magnetic chuck, a flat-topped box containing coils that become powerful magnets when current passes through them, is used extensively for holding flat work, but if the work is thin the wax should be used instead of the magnetic chuck, for the reason that the magnetic attraction is so great that a curved thin piece of work will be straightened against the face of the magnetic chuck, and if the surface of the work is ground or machined it is level until the current is turned off in the chuck and then instantly assumes its original curved state.

Making Upper Punch. *Transferring.* The lower punch is now finished, and its outline must be transferred to the punches of the upper part of the die. The small piercing punch *c*, Fig. 43, is the first punch to be permanently located in the punch holder and is left as previously described, $\frac{1}{16}$ inch longer than the larger trimming punches. The large blocks for the trimming punches are attached to the punch plate by screws, and while dowel holes are placed in the punch blocks, the dowels are not put in until after the punches are hardened. Having attached the upper punch blocks in place on the punch holder, the piercing punch is entered in the piercing die and the lower part is positioned so that its edge is parallel with the edge of the punch holder of the upper part. In this position the two parts are clamped, the outline of the lower punch is scribed on the face of the punches of the upper half, and the punch blocks then are removed from the punch holder.

Machining. The face of a block is placed against the solid jaw of a shaper vise, and a rod, say of ½-inch diameter, is placed between the movable vise jaw and the back of the punch. This insures the face of the punch being flat against the face of the solid jaw. If the rod were not used and the movable jaw should tilt slightly, as they invariably do, the work would be just as likely to lie flat against the movable jaw, which is then on an angle, as it would against the solid jaw, and the planed surface would not be at right angles with the face of the punch. By using a semicircular shaper tool the entire punch can be machined. For machining semicircles in the shaper, it is a good plan to turn up a disc, Fig. 47, and attach it to a tool for use in tool post. As the disc can be measured, it is much easier to obtain the proper radius by turning the disc than it is to file the radius tool accurately.

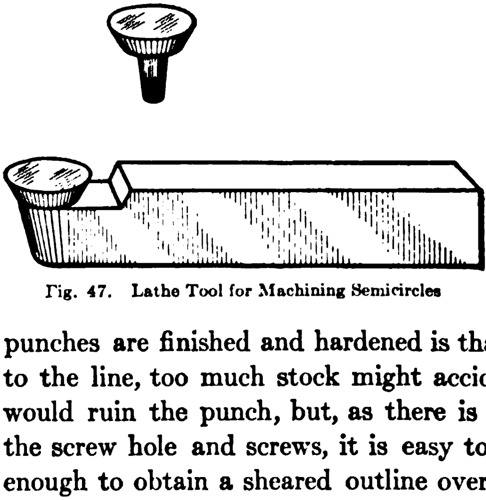


Fig. 47. Lathe Tool for Machining Semicircles

After all the punches of the upper half have been machined to the outline, they are then reassembled on the punch holder and the exact outline obtained by shearing. The object in leaving out the dowels until after the punches are finished and hardened is that, when milling or shaping to the line, too much stock might accidentally be removed, which would ruin the punch, but, as there is more or less play between the screw hole and screws, it is easy to move the punch over far enough to obtain a sheared outline over the entire contour. After shearing, say, $\frac{1}{32}$ inch deep, the punch should be returned to the shaper and the surplus stock carefully removed until the shaper tool just scratches the sheared part. This operation requires great care and the machine should be run slower than for ordinary work.

Locating on Punch Holder. After smoothing and filing the punches with a fine file the punches are hardened and located on the punch holder, and, when firmly pressed against the lower punch, the screws are tightened in the punches of the upper half. The dowel holes are then transferred from punches to punch holder and the dowels inserted. The faces of the punches are ground by plac-

ing the back of the punch holder on the bed of the grinder. A stripper to work between the punches of the upper half is made of $\frac{1}{4}$-inch steel and is attached to the punch holder by screws surrounded by coil springs. The counterbored recesses in the punch holder are considerably deeper than the heads of the screws, so that as the stripper is pushed back the screw head can travel in the counterbored recess.

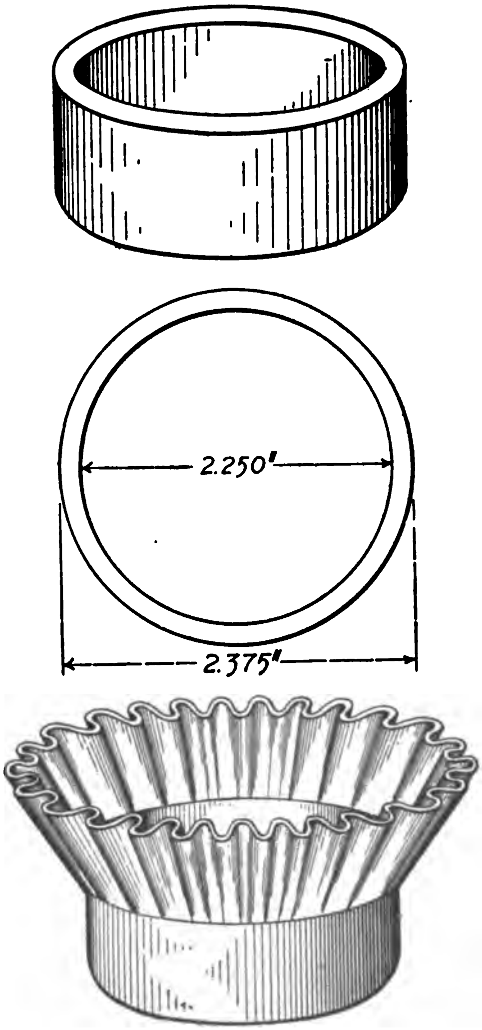


Fig. 48. Cup to Be Made by Drawing Dies

DRAWING AND FORMING TYPES

DRAWING DIES

Finding Size of Blank. Drawing dies as a rule are very simple to make, as the majority of drawn work is round, which means lathe work. Assuming that dies for the drawn cup in Fig. 48 are to be made, the first step is to ascertain the diameter of the blank when in its flat state. The thickness of the walls or side of the cup determines the diameter of the blank. For instance, if the cup is to be punched from $\frac{1}{16}$-inch stock, and the side walls and bottom must be $\frac{1}{16}$ inch after being drawn to a cup, the easiest way—if a sample cup is submitted—is to cut a round flat blank from same kind of metal and of the same

thickness and to keep reducing the diameter of the blank until it balances or weighs the same as the cup. Another way is to figure the area of the sides and of the bottom and to find the diameter of the blank having the same area. This latter method, however, is only approximately close, as the corners may be rounding in the cup making it difficult to figure.

Types of Die. In making the cup in Fig. 48, there are the following three types of forming dies that will produce it: (1) combination punch and die, Fig. 49, that punches out the blank and draws it to cup shape at one stroke in a single-action press; (2) combination blanking-and-drawing die, Fig. 50, for producing the cup in one stroke fitted to a double-action press; and (3) plain blanking die *a*, Fig. 51, and drawing die *b*, Fig. 51, which require two distinct operations, and this type of die can be used either in a single- or a double-action press.

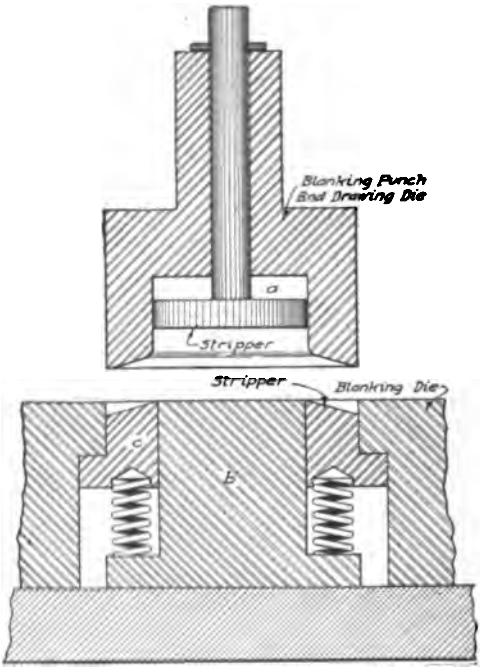


Fig. 49. Combination Punch and Die for Making Cup, Fig. 48

Making Combination Type. *Blanking Punch.* To make the die shown in Fig. 49 the punch is turned up on centers or may be made from the end of a bar held in a chuck. The size of the cup is $2\frac{3}{8}$ inches outside. This means that the drawing die *a*, Fig. 49, which is in the blanking punch must be 2.375 inches when finished. As the punch is apt to distort in hardening, and also in order to present a better wearing surface, there is a sufficient amount of stock left on the outside diameter for grinding to size after hardening, and when turning, the inside *a* is left a trifle smaller in order to grind. The amount to leave, depends upon the size of the job

at hand; in this case .015 inch or .020 inch would be ample. Care must be exercised when turning and grinding to have the inside and the outside concentric. The outside is ground to the desired diameter, using micrometers, and, to measure the inside, vernier calipers or inside micrometers are used. The corners of the drawing die must be ground rounding so they are concentric with the die, and the corners must be highly polished to prevent the metal dragging when changing from the flat state to the cup.

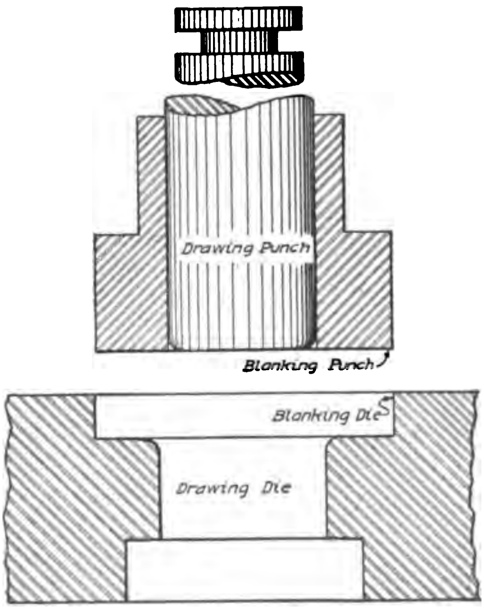


Fig. 50. Punch and Die of Combination Type

Drawing Punch. The drawing punch *b*, Fig. 49, also must be ground to size, and care must be exercised that the punch is exactly the right diameter. If the drawing punch is left .002 inch larger in diameter than the die less double the thickness of stock, it would cause the stock to be compressed, which, in the drawing operation, would lengthen the cup. To save stock, the cup could be made the same height using a smaller diameter blank, but the walls of the cup would be reduced in thickness; this means, of course, that the difference between the drawing punch and the die must be less than the thickness of the stock.

Operation Points. The points to be observed in drawing dies are: proper difference between the diameters of drawing punch and die; polished corners of punch and drawing die; and concentricity of inside and outside of drawing die and blanking punch.

Stock Wrinkling. The proper working of a properly made drawing punch and die depends upon the spring tension under stripper *c*, Fig. 49. If the tension is too great, the blank is held

between the faces of the blanking punch and stripper which often causes breaks in the corner of the cups. Again, if tension is not enough, the stock when changing from a flat blank to a cup forces the stripper down, which causes a wider space between the stripper and the punch than the thickness of stock. This is the cause of wrinkling of the edges of the cup as shown at *a*, Fig. 48. When wrinkles appear, increase the spring tension. Oftentimes the wrinkles overlap each other making a double thickness of stock to be crowded between the punch and the die where there is an allowance for only one thickness. This doubling of stock prevents the cup from passing through the die and as the punch continues downward the punch simply pushes the bottom out of cup.

The making of dies as shown in Figs. 50 and 51 is identical in operation with the foregoing description and the same points must be observed.

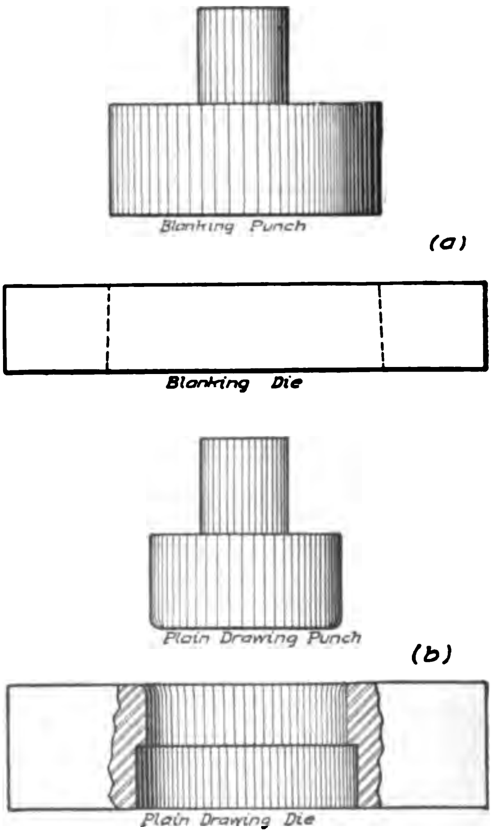


Fig. 51. Blanking and Drawing Punch and Dies Shown Separately

Irregular Drawing Dies

Method of Making. Drawing dies for irregular shapes are seldom made to blank and draw at the same stroke, one reason being that the shape of the blank often has to be changed owing to variation in thickness and hardness of the stock to be drawn.

To make a drawing die to produce the cup shown in Fig. 52 requires about the same procedure as to make a blanking die, except that in the drawing die the sides or walls are perfectly straight. The first step also is to make the drawing die, for before the blanking die can be made, the shape of the blank will have to be found.

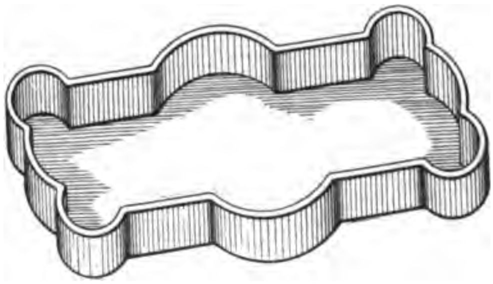


Fig. 52. Irregular Cup to Be Made by Drawing Die

Punch. The drawing punch in Fig. 53 should be made first. Assuming that the

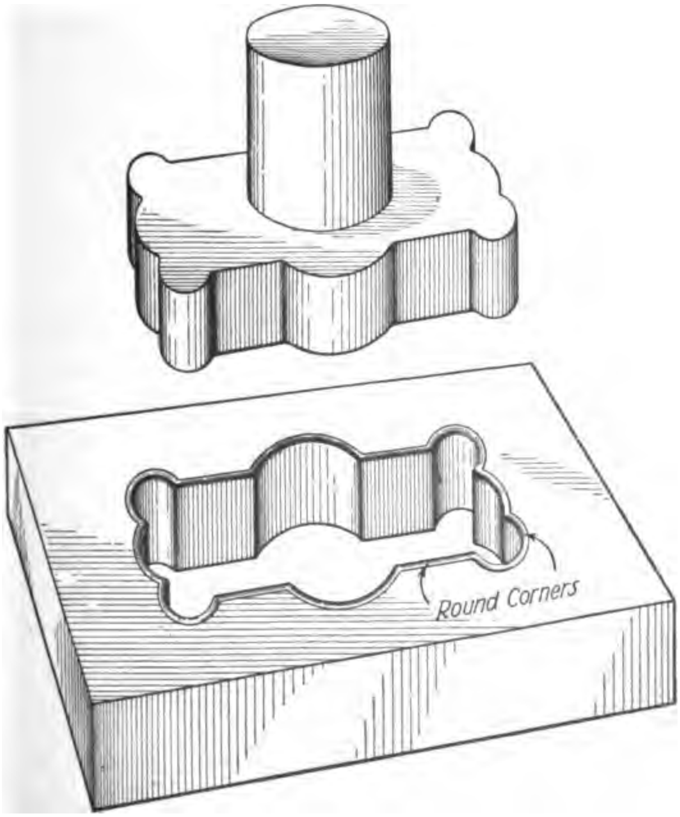


Fig. 53. Punch and Die for Making Fig. 52

punch has been machined to the overall size desired and has been blued on its face, we now lay out the outline on the face of the punch, and all lines on the punch face must be made from the same end and the same side. For instance, if the punch block in the rough state should not be parallel, and one line were scribed

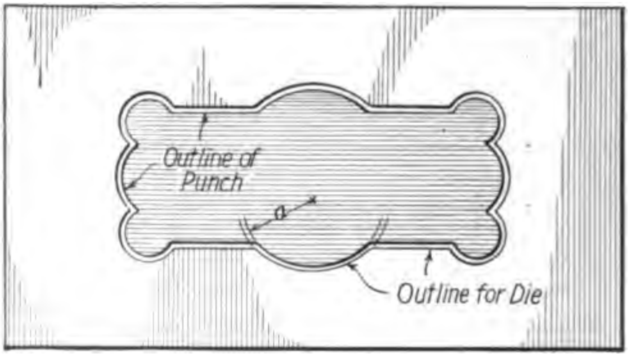


Fig. 54. Method of Outlining on Die Block

lengthwise of the punch from one side, then another line were similarly scribed from the other side of the punch, the two lines scribed would not be parallel. The punch should be machined between centers either on a miller or on a shaper.

The object in making the punch first is that its thickness and its length can be readily measured with micrometers, and when the punch is finished its outline may be scribed on the die, then parallel lines may be scribed around this punch outline a distance apart from the outline equal to the thickness of stock, Fig. 54.

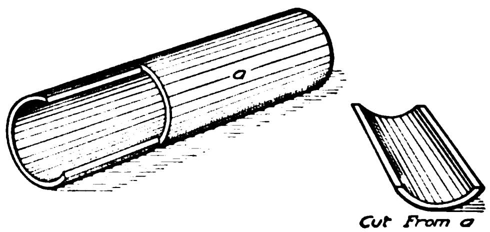


Fig. 55. Method of Determining Proper Size of Die

Die. The die outline is obtained by finding the radial centers of the circular punch outlines on the die, and scribing with dividers set as much larger as the thickness of stock, as at *a*, Fig. 54, then scribing the connecting straight lines. After machining the die nearly to the lines the punch should be used as a guide. By placing

the punch in the die, a piece of strip steel the same thickness as the stock to be used is inserted on each side between the punch and the die at the straight portion of the outline. For determining when the die is sufficiently larger a semicircular piece, Fig. 55, can be used; the semicircular piece being made by boring a hole in a piece of soft steel or brass the same diameter as twice the radius of the punch and turning the outside of the steel to a diameter of the desired die radius.

When sharp corners appear in the cup to be drawn, the die must have well rounded corners at the top gradually tapering to a sharp corner. If the cup to be drawn is of some depth, then two or more drawing dies are necessary. In this connection the draws are referred to as first, second, etc., and final. The first draw merely starts the cup to approximate shape, while the next draw makes the cup somewhat closer to finished shape, and the final draw completes the shape. Spring pads are used on practically all drawing dies.

FORMING DIES

Method of Making. Forming dies, while very simple in design and to make, often present difficulties, inasmuch as the metal being formed does not always form up to just the shape of the die or the desired shape. The forming punch and die can be made exactly the shape desired in the blank but the metal may *crawl*—the shop phrase for metal going where it is not intended to go—or the temper of the metal may play an important part, and even after the forming punch and die are made to produce the desired blanks the next shipment of metal may be of a different temper and the die must be altered.

There are no hard and fast rules to lay down for forming dies, except to allow for the double thickness of stock between the punch and the die. The making of forming dies is a cut-and-try method. One point must be borne in mind—if dies to produce a formed piece are to be made, the forming punch and die should be made first in order to determine the exact shape of the blank from which the blanking die is made.

EMBOSSING DIES

Embossing. Embossing means to raise a figure, or design, above the flat surface of sheet stock. In operation the best results are obtained from the blow by attaching the force, or punch, or male member of the die to the hammer of a drop press.

Die Sinking. There are three methods of making embossing dies, and to employ any of the methods the workman must be an artist, for the outline of the design must be transferred from a sketch or possibly from a sample to the face of the die—if the design is of a floral or landscape effect, it means freehand sketching to obtain the desired outlines on the die face. Embossing dies proper, as well as drop-forging dies, are distinctly apart from the work expected of tool-makers or blanking die-makers, and embossing die-makers are known as die-sinkers.

Hobbing Methods. The method most generally used is known as the hobbing method. A male member or hob is made, as in Fig. 56, which is for a suspender buckle, and when finished the hob is hardened and forced into the face of the die block. This operation can be done either (1) cold, using hydraulic pressure, or (2) a flat-face punch can be attached to the hammer of a drop press, the die block heated to a bright red and placed in the drop press, and the hob placed in position on the face of the die block, the hammer then being allowed to fall, and forcing the hob into the hot die.

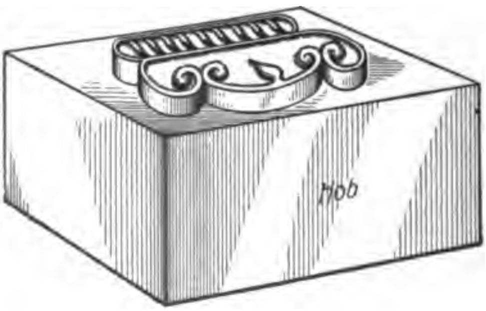


Fig. 56. Embossing Die on Hob

When the latter method is used, however, the design as forced into the die block is rough, due to oxide scale from heating and cooling the die block. Also there is ⅛-inch shrinkage per foot to molten steel, and the shrinkage of steel when only red hot is considerable. However, the rough design is in the die block, and with semicircular, diamond-point, and flat engraving tools the figure is finished and smoothed with die-sinkers' files called rifflers. The final polish necessary in an embossing die is obtained by using the end of a small stick of wood and loose emery; every part of the design in the die must be free from scratches, for any mark in the die will be transferred to the work.

Reverse Cutting. The third method is to cut the design directly in face of the die block. To do this the die-sinker must cut the design

the reverse of that desired, which is the most difficult method. Wax is used to obtain the impression. The surface of the die block or impression is smoked with a match to prevent the wax sticking and when the wax is forced into the impression in the die the wax shows

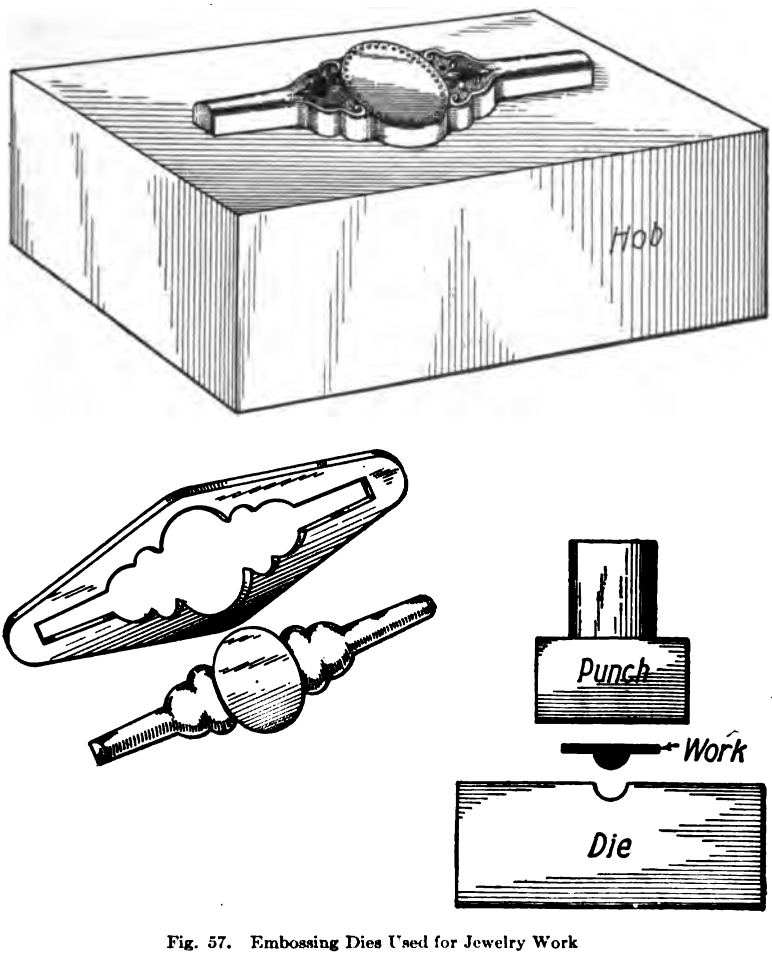


Fig. 57. Embossing Dies Used for Jewelry Work

the design and is the die-sinker's guide. The force or punch is made by shaping its end to practically the same outline as the depression in the die, and by forcing it cold into the die by hydraulic pressure, or the die may be fastened to the bed of a drop press and the force attached to the hammer and forced into the die, either hot or cold.

After a complete impression has been transferred from the die to the force the design on the force must be made smaller than the die to allow room between force and die for the stock to be embossed.

Jewelry Dies. Fig. 57 shows another style of embossing die which is used extensively for finger rings, breastpins, etc. The die shown is for a ring, and in operation the piece of gold is placed over the design in the die and a flat punch strikes the gold, forcing the design in on one side only. The piece of gold is then trimmed in a punch and die called a trimming die, which is nothing more nor less than a plain blanking die.

FLUID DIES

Usage. There are many articles that can be formed by filling a cup with soapy water, placing the cup in a die, and allowing a punch—preferably in a drop hammer—to strike the contained water and to force the metal of the cup into the design of the die. Door knobs, watch cases, and umbrella handles are of the class of work that can be done profitably with fluid dies.

A power press is not suitable for forming with water as water will not compress and the travel of the press is so slow that, unless a perfect fit is made between the punch and the die, the water escapes and there is not pressure enough to force the metal. On the other hand, if a perfect fit is made between the punch and the die, the water acts as a solid mass, and the crank shaft of the press would be sprung, if not broken. Water for forming or embossing is only used when the forming takes place on the side of the cup, as shown in the pieces in Fig. 58. Any design or shape on the end of the cup could of course be done in a plain die and struck with a punch.

Operation of Fluid Die. Water forming dies, Fig. 59, are made in halves, one half stationary and the other movable, so that work can be removed after forming. Referring to *a*, Fig. 58, which is an umbrella top, it requires a cup formed as at *e*, Fig. 58, prior to forming in the fluid die. In operation a quantity of these cups in their plain state are placed in a pail of soapy water, the operator by moving the lever, *a*, Fig. 59, opens the fluid die, and, as a cup when removed from the pail is full of water, the cup is carefully placed in the die so as not to spill the water, and the die is closed. Generally a locking device is attached to the die to prevent its flying open when the punch strikes the water.

Hammer Blow. The height of fall of the hammer containing the punch must be determined by experiments on each type of blank. When the proper height is found that will give the full design on the cup, the press hammer is set so that the fall will be uniform for each blank. The hammer must also be a perfect fit

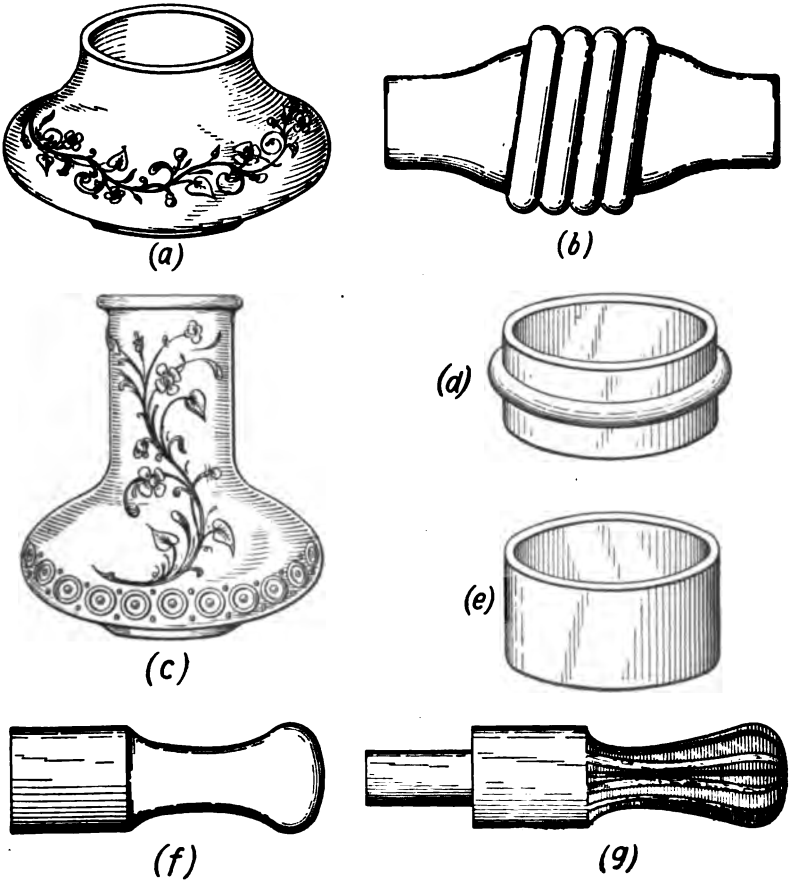


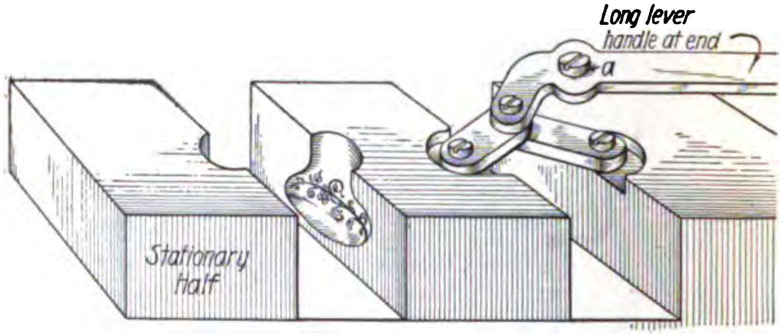
Fig. 58. Examples of Work Done by Fluid Dies

between the uprights or ways of the drop press, for the punch must fit the upper opening in the die to prevent the escape of water, and a loose hammer would cause the punch to strike on the corner of the die, not only breaking the corner and the punch, but preventing the full blow on the cup. Also it is dangerous to the operator, as

the small pieces that break from punch and die travel at tremendous speed.

It is noted that the design is cut in the die shown in Fig. 59, but this is not essential as the design can be rolled in the plain blank and the height or blow of hammer regulated so that the swell or enlarged diameter on the blank can be obtained without marring the design.

Substitute Processes. *Use of Rubber Core.* The piece shown at *b*, Fig. 58, is a handle, and to make this form a cup would require



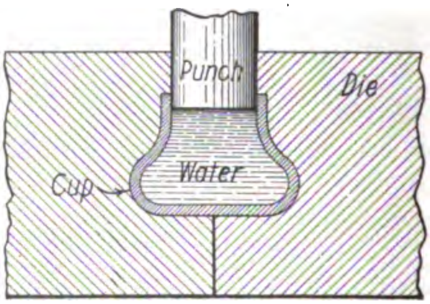


Fig. 59. Method of Operating Fluid Die

several redrawing operations and annealings before the cup was in the shape required for forcing in the design. A piece of tubing is cheaper, but as the tubing will not permit filling with water, work of this character having open ends is formed by placing a long bar of spring rubber in the cup after it is in the die. Rubber merely changes form but does not set, and when the punch strikes the rubber the rubber flows to the unsupported part of the tubing in the die which of course forces the tubing into the design in the die. The

rubber assumes its original shape as soon as pressure is relieved and it then is readily removed.

Roller Dies. The pieces *b* or *d*, Fig. 58, could also be made by the rolling dies in Fig. 60. The arbor *a* that the cup or tubing is placed on is considerably smaller than the inside of the cup or tubing, to allow the removal of the finished part. The female roll *b* is attached to the cross-slide of the rolling lathe or the roll dies can be used in an ordinary lathe by gripping the male member *a* in the

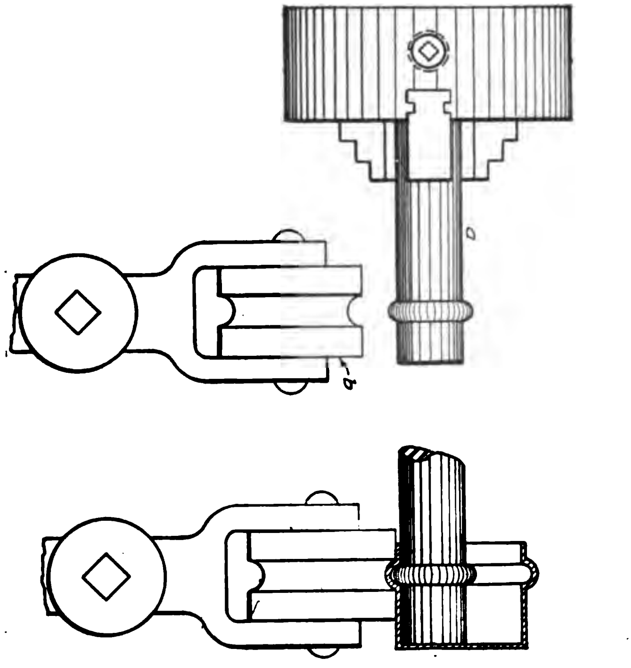


Fig. 60. Rolling Die

lathe chuck and the female roll in the tool post of the lathe. In operation the cup or tube is placed on the revolving roll in the chuck and the roll *b* is brought to bear against the work. The friction between the two rolls and the work is sufficient to cause the work to rotate, and as the cross-slide of the lathe is moved toward the center of the lathe the beading or form is transferred from the rolls to the work.

Forming of Die. *Locating Hole.* When making fluid dies the two halves are machined exactly the same height, and the faces

that come in contact with each other when the dies are together must be at right angles with the bottom. The two pieces are either screwed to a plate or attached to a special holder so that one half can be removed and replaced and the plate strapped to the face-plate of a lathe. A fine prickpunch mark is placed exactly on the line where the two halves meet and the prickpunch mark should be in the center of the two halves. If the prickpunch mark is indicated true, the hole will have half its diameter in each half of the die block; otherwise, one half will be of a greater diameter and trouble will be experienced in removal of the formed cup. The stock is removed in the usual way by spotting with a flat spotting tool, Fig. 61, rigidly held in the tool post to insure the spot being true, as the spotting tool actually bores or turns the recess spot which is to be the starting point for the drill that removes the stock. The angle of the spotting tool and the drill should be the same.

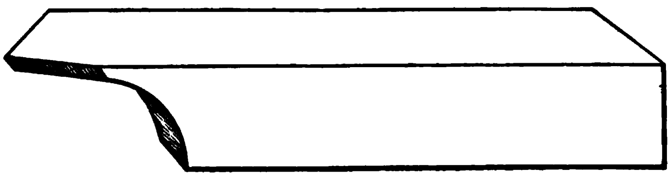


Fig. 61. Cutting Tool Used for Fluid Die

Drilling. Good results cannot be obtained by holding an ordinary drill in a chuck in the spindle of the tailstock of a lathe as there is too much spring due to play between the spindle and the hole of the tailstock, and due also to the spring of the drill, chuck jaws, and spindle of the tailstock, which is greatly increased as the distance from the point of the drill to the tailstock is increased. A mark, or a piece of wire is placed on the drill the desired distance from the point of the drill to act as a guide for the depth to be drilled. If the drill is too large to enter the tailstock chuck, a dog may be fastened to the shank of the drill, using a thin piece of sheet brass between the drill and the dog to prevent marring the drill, and, by placing the center of the tailstock in the center of the drill and allowing the tail of the dog to bear on the seat of the tool post, the hole can be drilled.

A tool should be fastened securely in the tool post of the lathe and the tail of the dog should just touch the tool when the center

of the tailstock is bearing on the drill center, and as the drill is fed into the work the carriage of lathe should also be moved along at exactly the same rate of speed, always keeping the tail of the dog bearing against the tool and also bearing on the seat of the tool post. If this is not done, the drill is likely to draw in, especially so if the drill passes clear through the work, and, as the drill catches or draws in, the center of the drill is pulled away from the lathe center in the tailstock, and the drill then rotates with the work. The object of having the tail of the dog bearing against the tool in the tool post is to enable the die-maker to hold the drill on the center of the tailstock. Under no circumstances should the dog be held by hand, either when drilling, or when removing the drill, while the lathe is rotating. The pressure and blow of the tail of the dog when a 1-inch drill catches in the work is sufficient to crush a hand or to sever a finger. Many fingers are lost in this manner.

It is appropriate to mention the danger when attempting to hold work by hand in drilling with a drill press. Always bolt the work to the table if the work is large or thin, or hold the work against a rigid stop on the drill-press table, and if the work is small it can be held in a large clamp or wrench. Thin work catches on a drill more often than heavy pieces, due to the point of the drill passing through the work before the body of the drill enters, and the work will run up the spiral of the drill to the end of the spiral, then rotate with drill. At times the work simply tilts at an angle and instantly assumes the same number of revolutions as the drill, and severe lacerations are the result if work is held by hand. The writer once had a $\frac{3}{4}$-inch drill catch in a drop-forge die block that weighed 112 pounds and the block was whirled, nearly upsetting the drill press, and finally the drill broke and the block was hurled some distance from the press. Emphasize again the tool-makers' slogan—"eliminate all chances".

Boring to Form. Having drilled the hole in the fluid die to proper depth, the form is now bored. This involves the use of a blanked piece of steel, *f*, Fig. 58, that was previously turned the exact shape desired or rather the shape of the desired cup. By using formed boring tools the impression in the die is made to absolutely fit piece *f* when the dies are closed. As the larger diameter of the die is *blind*, that is, cannot be seen when boring, the shape is deter-

mined by placing an even light coating of Prussian blue on the model piece *f* and rotating piece *f* when the die halves are bearing against it. A streak or streaks of blue will show in the die and by moving the movable half of the die the die-maker is enabled to see the work and to set the boring tool so that it will cut exactly on the streak of blue paint. This type of lathe work requires patience and skill, and several specially made boring tools of different radii.

Forming with Cherry. Another way in which this type of die can be made is to bore the die as above, almost to size and shape, and to finish the die in a drill press by having the model *f* of tool steel with teeth cut in it, *g*, Fig. 58, as in a formed milling cutter. The formed cutter, which is called a cherry, is hardened, and is gripped in a drill-press chuck, and the dies closed on the cherry. As the cherry revolves, the two halves which are held between clamps are closed onto the cherry, which cuts the desired form. The drill press must be stopped frequently and the clamp removed and the chips cleaned from the cherry, as there is no chip escape; plenty of oil should be used. If the design of die is not too intricate, however, the lathe method is quicker and in most cases better.

Cutting Design. Having obtained the desired shape in the die halves, the next operation is to cut the design. It is obvious that the hob method cannot be used in a die made in halves, as the design on *a*, Fig. 58, encircles the blank, and, if a hob were made having the design extending the entire circumference, the action of the hob when closing the two halves on it would be that the raised figures on the hob would cut away the die halves in a straight line. Therefore, the design must be cut in by hand, and the design must also be laid out in the die halves the reverse of that desired on the finished cup.

Transferring. There are several methods employed in transferring the outline of the design to the die. One method is to make a transferring roll, of material similar to printers' rolls and of the same shape but a trifle smaller in diameter than the bored portion of the die. The roll has a central hole its entire length, and larger in diameter at the top. The design is now sketched on a piece of thin paper which is exactly the same length as the circumference of that portion of the die having the figures, and after the design is

accepted the lines of the design are inked, using slow drying printer's ink, and the paper strip is pressed into a straight piece of wood which has been grooved the same shape as the contour of the die and the composition roll, as in Fig. 62. By rotating the composition roll from one end of the paper to the other the ink is picked up on the roll. Then, by cleaning the die thoroughly and placing the composition roll in the die and forcing a round plug in the small hole in the composition roll, the roll is expanded to fit the die and the ink from the roll is transferred to the die. This method only gives the general design and its location, as the ink will spread somewhat. With an engraver's point, which is a fine oil stone in the form of a

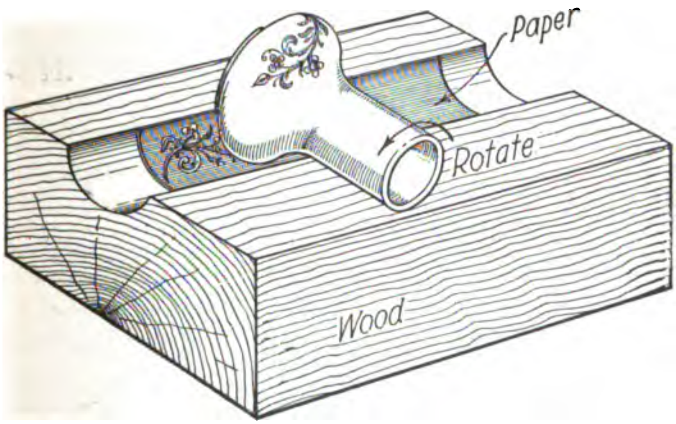


Fig. 62. Rolling Die with Composition Roll

lead pencil, or with a sharp scriber, the outline of the design is scratched in the die.

Finishing. From now on the work is strictly die-sinking and engraving, using small curved cold chisels to remove the bulk of the steel, shaping with engraving tools of various shapes, and lastly smoothing with files and wood stick with emery.

Die-sinker's wax is used for proving, and by smoking the surface of the die and forcing in the wax the impression as it should be on the cup is formed in the wax. The wax should be examined closely to find if any portion of the figure of the design is distorted, for an undercut on any part of the design will prevent the cup from being removed after being forced into the die.

DROP-FORGING DIES

Typical Operation. When the term drop-forging dies is used it is generally understood to mean forging dies for forming red-hot metal. In operation these are two die blocks—upper and lower—as in Fig. 63. The upper half contains one half of the impression and the lower block the other half of the impression. The upper half is keyed to the hammer or drop by means of the dovetail shank, and the lower block is similarly secured to the bed of the drop press.

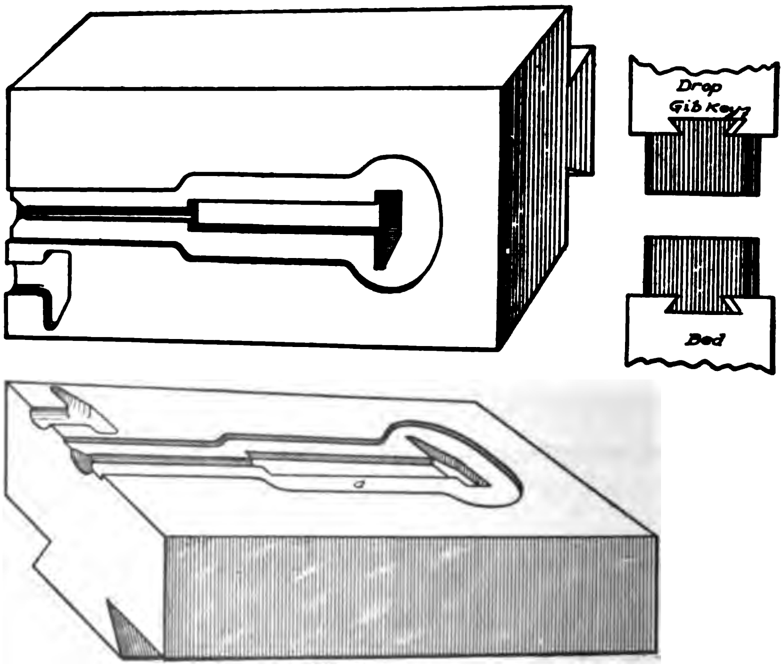


Fig. 63. Typical Drop-Forging Die

The impressions are so laid out that when one end and one side of each block are even the impressions are opposite.

Breaking Down. At one side of the impression proper is another impression called the break down. A furnace nearby contains a number of bars of metal which are heated on one end to a bright forging red. The red-hot end is placed over the break-down impression, and the drop is allowed to fall by tripping with a treadle. The blocks on coming together smash the heated bar into the break-down

impression. The object of the break down is to allow the use of a smaller bar of metal and by being formed in the break down the shape of the heated end is formed and flattened so that there is metal enough to fill the impression proper. The instant the blocks come together there is a rebound and the treadle should be released to allow instant raising of the drop which is lifted by a board fastened to it at one end. The board passes between two revolving pulleys that grip it, and the hammer is raised by friction to a slight distance above an automatic stop or pawl, at which point the rolls separate and the drop rests on the pawl.

Forming. The heated bar is now placed over the die proper, and enough blows are given the bar to fill the die completely. At

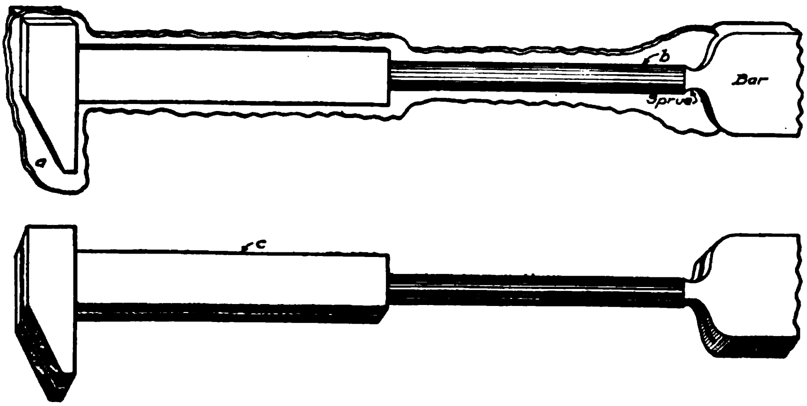


Fig. 64. Drop Forging Showing Flash Attached and Flash Removed

each stroke, however, the heated end should be raised from the die to allow the loose oxide or scale that may have formed to be blown or brushed from the lower die. Another reason for removing the bar a short distance from the die each stroke is to prevent heating the die unnecessarily. As there is generally more metal in the heated end than is necessary to fill the die, it is obvious that some of the metal will be forced out between the dies in a thin web—called the flash—*a*, Fig. 64. To permit the dies coming together and forming a piecé to correct diameter, a recess, *a*, Fig. 63, is milled around the die for clearance for surplus metal or flash. There is a small connecting portion, *b*, Fig. 64, between the forged piece and the bar, called the sprue, which should be as small as possible.

Trimming. After the piece has been forged, it is then placed over a die having an open end to allow the passage of the sprue and called the trimming die, and the punch—being shaped to fit the forging to prevent its distortion—on descending, trims the flash from the forging and leaves the bar and forging as at *c*, Fig. 64.

The sprue is then placed between two knives that are chisel-shaped punches fitted in an ordinary punch press, and the finished forging is severed from the bar.

Methods for Saving Material. *Tapering.* If the work is of the type shown in Fig. 65, which is a bicycle crank having a large portion and tapering to a small end, the method of forging is somewhat different—mostly to effect a saving in material. The rods are purchased a trifle larger than the largest diameter and cut to short lengths while cold in a large pair of power shears. These pieces are then heated to forging heat and forged tapering under a trip hammer, the hammer being fitted with two small blocks or dies with plain cylindrical impressions, and making several hundred blows per minute. By gripping the end of the rod in tongs the rod is worked back and forth while the hammer makes rapid blows on the work, which reduces or draws the stock to proper length and size. The success of this operation depends solely upon the skill of the operator, as the blows are so rapid and always at same point that if the operator fails to move the rod or turn it fast enough the work will not be round or tapered. In other words, the trip hammer produces the same work that a blacksmith would produce by hand hammering except in much quicker time. The forged piece is bent at right angles, then reheated, and afterward placed in a drop die for final shaping.

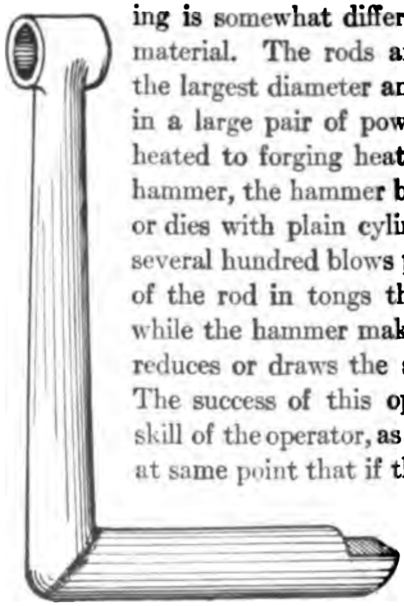


Fig. 65. Drop Forging with Tapered Stock

Spreading. Fig. 66 shows another type of forging which is a sprocket wheel, and to produce this forging in one die would mean a tremendous loss of metal as the hub is so much thicker than the rim. If a thick piece of steel were placed over a center die and an attempt made to flatten the steel until it filled the die, it can be

readily seen that, as the stock began to flow outward toward the rim of the die, it would flow in all directions, and the metal that would be forced into the spokes would be gradually pushed sidewise, or distorted. Therefore a smooth-face breaking-down die is used to form the hub and to spread the steel enough to completely cover the finishing die, after which the steel is reheated and final-formed in the finishing die.

Shaping Die Block. *Setting-Up.* The first step in making drop dies is to select the die blocks; they must be large enough for the job, for the impression must not come too close to the edge of

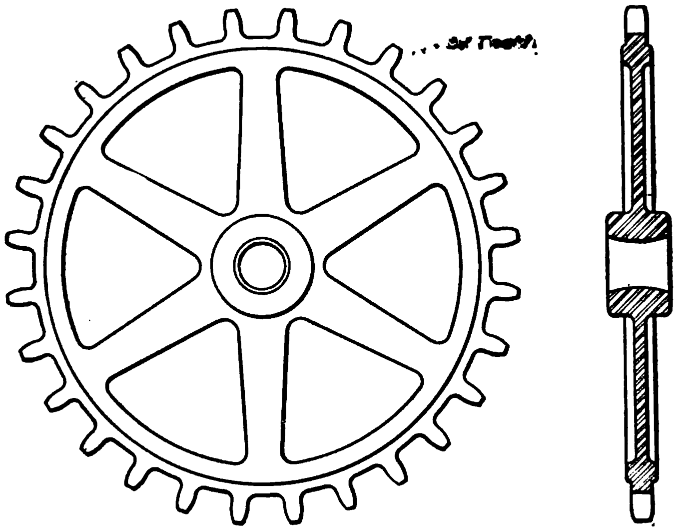


Fig. 66. Sprocket-Wheel Forging

the blocks. A hole, say $\frac{5}{8}$ inch in diameter, is drilled in each end of each block about $\frac{1}{2}$ inch deep and approximately central in the end. Then the block is placed, with its level surface down, on a planer bed, and with finger straps engaging the holes in the ends and properly blocked up, as in Fig. 67; the die block is now brought to bear against a parallel strip that is parallel with the travel of the bed and that is clamped to the planer bed. The object of this parallel strip is that it not only aligns the edge of the die block with the travel of the planer bed but prevents the block from shifting when planing on the extreme edge, which is likely to happen as the block

is clamped in the center by the fingers only. When a rough casting or forging is clamped to any machine bed or in any machine vise, it is good practice to place a thin piece of metal or cardboard between the clamped surfaces to prevent marring the machine surface. If the planer vise is large enough to hold the die block, there is of course no advantage in using finger straps and bolts, providing the solid vise jaw can be readily aligned with the travel of the bed.

Forming Dovetailed Shank. Having secured the block to the planer, a cut is taken across the top, and, chalking or coppering the

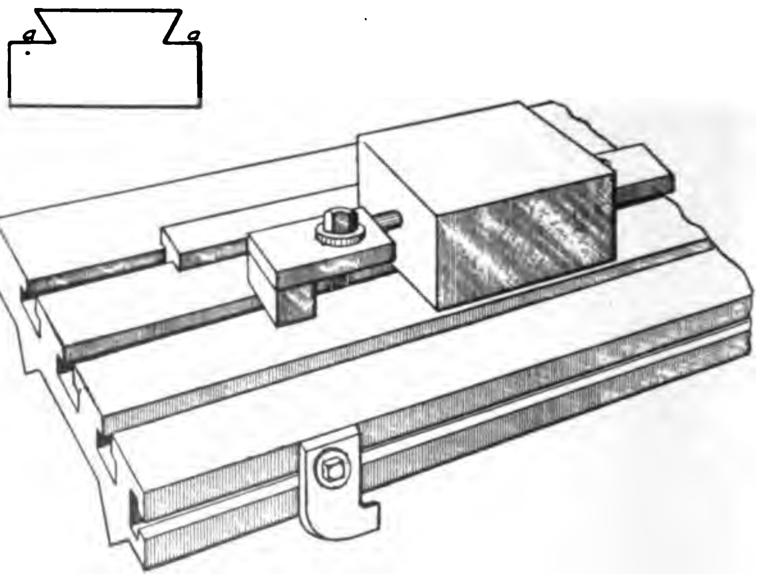


Fig. 67. Shaping Die Block for Drop Forging

top, the width of the dovetail is scribed on the face. The stock is then planed away and the angle forming the dovetail is planed. Should the angle be 30 degrees from the vertical the head of the planer is set at 30 degrees by means of the graduated dial, and the flop which carries the tool should also be set way over in the same direction that the head is swung, to prevent the tool gouging in on the back stroke. Some tool-makers lock the tool so that on the back stroke the tool drags in exactly the same line as on its forward or cutting stroke. This is not good practice, however, for the back drag causes more wear on the tool than the cutting or forward stroke.

The dovetail shank is planed to fit a templet, and the angular sides must be smooth and straight, for any irregularity of surface prevents the long taper key from properly holding the block. For instance, should several ridges stand out on the angular sides of the shank due to uneven planing, the key would bear only on these ridges, and after a few blows when in the drop press the ridges would be likely to flatten, causing the key to become loose. The shoulders *aa*, Fig. 67, must be on a line; in order to obtain the best results, both sides are roughed nearly to the line, and the last chip

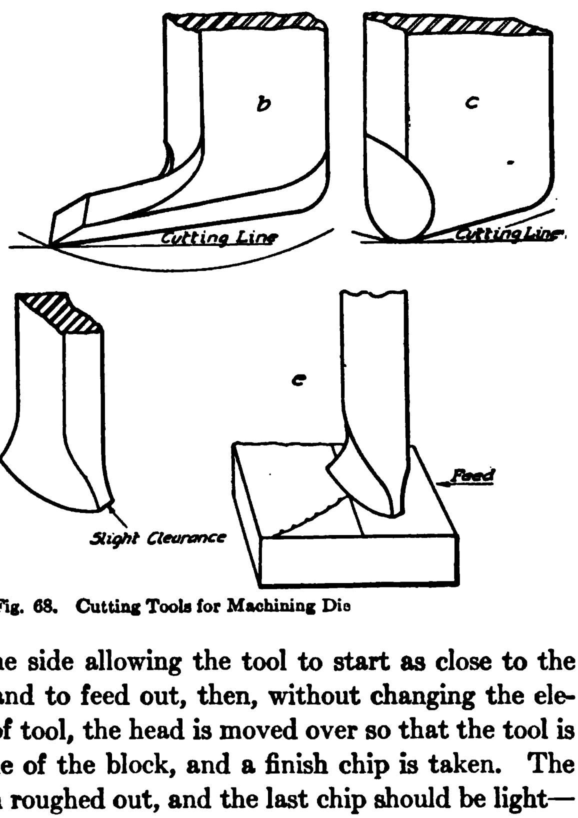


Fig. 68. Cutting Tools for Machining Die

is taken first on one side allowing the tool to start as close to the shank as possible and to feed out, then, without changing the elevation or position of tool, the head is moved over so that the tool is on the opposite side of the block, and a finish chip is taken. The angle sides are then roughed out, and the last chip should be light—a rigid keen cutting tool being used.

For roughing out any heavy work the roughing tool *a*, Fig. 68, is best adapted. The diamond point should not be used for heavy cuts unless the cutting point is on a line with the tool face that the tool-post screw bears against. By referring to sketch *b*, Fig. 68,

which is a diamond-point tool, the cutting point is seen to be so far advanced from the line of tool support that any springing of the tool would cause it to dig in, as will be understood by noting the line showing the radius traveled by the tool point in springing. It will be noted that the lowest point of the radial line is below the line of the cutting surface. By using a roughing tool, as at *c*, Fig. 68, the springing tends to force the tool away or above the cutting line.

Machining Top and Edges. Having fitted the shank to the templet, the straps can be removed and the die block fastened to the bed, shank down, and the edge of the shank brought to bear against the parallel strip. The top surface is machined sufficiently to obtain a true clean surface, and the final cut should be taken with a spiral finish tool, *d*, Fig. 68, for the top must have the die outline laid out on its surface, and a rough surface makes it difficult to see the scribed lines. The finishing tool when working is shown at *e*, Fig. 68.

One top edge of the block is machined by using the down feed to a distance of, say, 1½ inch on one side only. The block is then turned crosswise of the planer, and the top edge of one end is planed down the same distance. The machined edges of the end and side must be at right angles, for from these two machined surfaces—on both blocks—the dies are laid out, and the machined surfaces or edges are also used to set up the dies in the press by bringing the edges and ends in line with each other.

Squaring. One way to square up the block so that the machined edge will be at right angles is the old-fashioned cut-and-try method —that is, to set the block as nearly as possible by using two squares, one against the cross-head of the planer, and the other along the machined edge of the block. After the first cut is taken down, a square is tryed on the block and the block is shifted a trifle, etc., until the end and the side are square—the shop term for being at right angles. This is a slow method, and a more workmanlike one is to clamp an indicator to the planer tool held in the tool post, allowing the pointer of the indicator to travel along the edge of the square blade while the base of the square is held against the side of the block. The pointer of the indicator will remain at the same point when the block is exactly square.

Recessing of Die. *Laying Out.* After finishing the tops and

the edges of both blocks the top surfaces of each are smoothed with emery cloth on a file. A center line is drawn lengthwise of each block by using a sliding-blade square as at Fig. 69 and a cross-center line is scribed also. Scribing the line on each block with the

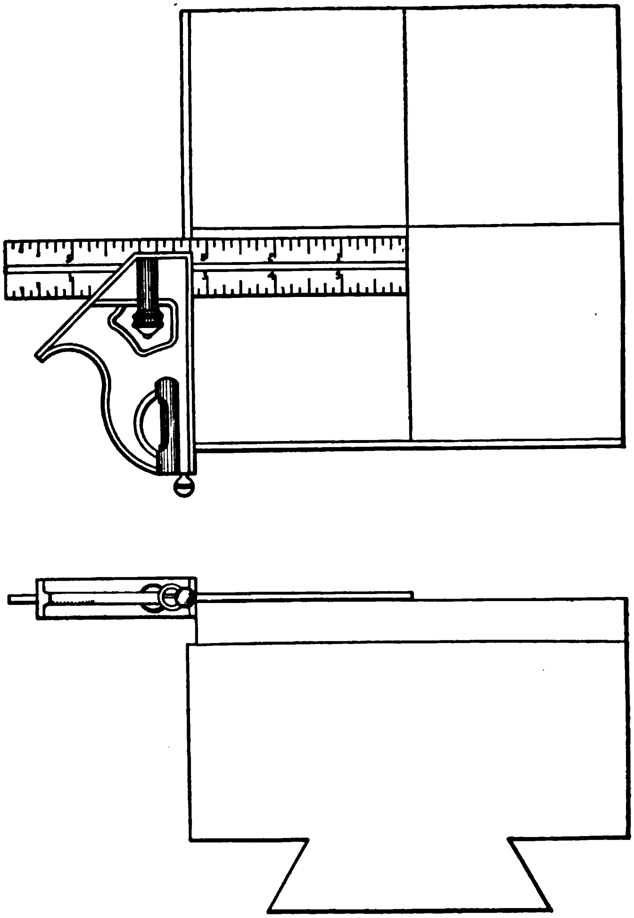


Fig. 69. Sliding-Blade Square Used for Laying Out

same respective settings of the square—working from the end and side of each block, and scribing along the end of the blade of the square—insures the center of the cross-lines being the same on both blocks.

Assuming that the die is to be laid out to produce the forging of the sprocket wheel shown in Fig. 66, the first move is to place a

fine prickpunch mark at the intersection of the lines on both blocks. As this particular forging is round, both blocks may be laid out exactly alike, but in the laying-out of forgings, such as Figs. 64 or 65, the outline of the forging must be laid out right and left, so that the outlines will match when the faces of the blocks are together. The center circle for the hub is scribed with dividers, as are also the circles for the rim, the inner diameter of rim, the circle for the diameter at the bottom of the teeth, and the outside diameter. The

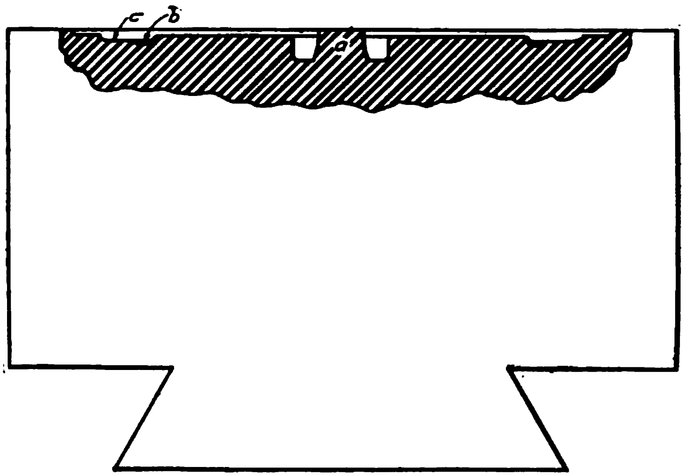


Fig. 70. Elevation of Die Block, Showing Shape of Lugs, Etc.

spokes are now laid out at right angles with each other, using a sliding-blade square.

If there is a dividing head on the milling machine or die-sinking machine, it is unnecessary to lay out the teeth, as a cutter of the right shape may be used and a tooth can be cut into the outside line, then the index shifted for the next tooth, etc. If it is necessary to cut the teeth by hand, then of course each tooth must be carefully laid out.

Forming. The die block is fastened to lathe the faceplate, and the prickpunch mark is indicated true. The recess for the hub of the forging is turned in the block the proper depth and tapering. Usually 5 degrees clearance is given on drop-die work of ordinary depth, and if the forging is somewhat deep, say 2 inches, 10 degrees is better; it is obvious that straight sides in the die would cause the

metal to stick so that the red-hot bar would not be stiff enough to pry the forging from the die. The center lug *a*, Fig. 70, for forming the hole in the hub may be made solid or inserted, as suits shop practice. At the same setting the rim *b* and the flash clearance *c* are turned in the die. When turning the rim it is well to use a formed turning tool that gives the proper angle to the side of the rim and at same time shapes the bottom of the rim.

The spokes are milled or cut in the shaper. The spokes and teeth can best be done on a die-sinking machine, which is a vertical milling machine having the dividing head on a table in the horizontal plane.

Dies for forging sprockets and similar work are extremely simple to make as the work is mostly lathe work. The die for producing the monkey wrench, Fig. 63, and for the crank, Fig. 65, are also easy to make, as the die can be cut out in a shaper or a milling machine, except for the sharp corners which have to be chipped out by hand using a cold chisel and hammer.

Completion of Die. *Shrinkage Allowance.* As steel in the molten state shrinks $\frac{1}{8}$ inch per foot when cold, every dimension given on the blue print must be increased at the rate of $\frac{1}{8}$ inch per foot to allow for shrinkage. For instance, if the finished diameter of the sprocket forging, in Fig. 66, called for 12 inches, the diameter of the corresponding recess on the die in Fig. 70 should be $12\frac{1}{8}$ inches, or if the diameter is 6 inches, then allowing for shrinkage the die must be $6\frac{1}{16}$ inches, and if the forging is to be 3 inches the die must be $3\frac{1}{32}$ inches, etc. There are shrink rules or scales on the market that instead of being 12 inches long are $12\frac{1}{8}$ inches long, but the graduations are the same style as on an ordinary scale—in inches, from 1 to 12. In other words, the $\frac{1}{8}$-inch shrinkage allowance is taken care of by being evenly distributed throughout the $12\frac{1}{8}$ inches. All that is necessary, with this scale is to set the dividers to, say, 6 inches on it, and they are really set at $6\frac{1}{16}$ standard inches.

Matching. When making drop dies having round or tapered parts, as in Fig. 65, it is a good plan to turn up a piece of steel at the proper taper, or to the proper diameter if the work is straight, and to use this piece as a templet, with which, by placing an even thin coating of Prussian blue on the templet, the trueness of the recess in the die can be tested frequently. When both halves of the die are

finished and the impressions are smoothed nicely, the blocks may be placed face to face, and, after slightly warming the blocks, the impression may be filled with molten babbitt. Babbitt does not shrink very much and the babbitt test piece may be examined to make sure that the impressions in each die match. Also the babbitt may be measured to check diameters and length.

Hardening. The dies are hardened by being heated face down on a charcoal fire, and, when heated to a depth of several inches, by having a heavy stream of water played on the face of the die. Cast-iron dies may be used when only a few hundred forgings are required.

Dies for Trimming. Trimming dies are usually made in *halves* to facilitate making, and are also frequently made of machine steel and casehardened as the forging is red hot when trimmed. If the forging is thin or light, the flash would cool so quickly that soft dies would be out of the question. The punch, however, can be casehardened.

The clearance on trimming dies varies from 5 degrees to 10 degrees, according to the nature of the forging. In any case the forging must be able to pass through the die without being distorted. Trimming dies are open at one end to allow the sprue and rod to pass through, for the forging should stay on the rod as it often happens that the forging becomes distorted during trimming and it is necessary to strike it between the drop dies for final shaping of the forging.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

MACHINE SHOP MANAGEMENT

1. Why were the early New Englanders forced to become manufacturers?

2. What was the occasion of the first *boycotting* movement in this country?

3. What is meant by a *combination of capital?*

4. Describe the operations carried on by a combination of capital in acquiring possession of various small plants in the same line of manufacture.

5. What is *interchangeable manufacturing?*

6. When were milling cutters first made?

7. Who introduced interchangeable manufacturing in this country?

8. What invention brought Eli Whitney into public notice?

9. What are the principal objects sought in modern manufacturing?

10. How can you account for the largely increased output per employe of the present day as compared with former times?

11. What is meant by *machine shop management?*

12. What are the principal departments of a manufacturing plant building machinery and like products?

13. What are the secondary departments or rooms?

14. Where is the power house usually located, and why?

15. What is meant by *lines of authority* in shop organization?

16. What is the regular channel of official communication rom the general manager down to the workmen?

17. What is meant by the *police regulations* of the shop?

18. What officials enforce the police regulations?

19. How would you seek to promote the loyalty of the working force?

20. What is meant by the *suggestion system?*

21. What are the seven principal requirements of shop methods and records?

22. Describe the necessary steps in the employment of workmen, from the application for a position to setting the man to work.

23. How are records of individual standing determined?

24. What usually constitutes the largest item of cost in the manufactory?

25. What is a *time recording clock?* How is it used?

26. What is a *production order?*

27. With what officials do production orders originate?

28. What is a *plant order?*

29. How are stock and material obtained from the storeroom?

30. How are orders traced and followed through the different departments?

31. How are tools obtained from the tool room?

32. How does the tool keeper ascertain who has certain tools?

REVIEW QUESTIONS

ON THE SUBJECT OF

METALLURGY

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1. (a) What is a metal? (b) What is metallurgy?

2. Tabulate the comparative reducibilities of the metals.

3. What is meant by reducibility?

4. State and discuss briefly the various physical properties of interest in metallurgy.

5. (a) What is the importance of sampling? (b) Describe a method for getting a proper sample.

6. State and describe the various processes used in ore dressing.

7. Tabulate the various styles of furnaces used in metallurgy.

8. List the refractories used in furnace linings.

9. Sketch and indicate the essential features of an iron blast furnace.

10. Describe the operation of such a furnace.

11. Discuss the chemical and physical properties of pig iron.

12. Sketch and indicate the essential lines of the iron carbon equilibrium diagram. Define each term used.

13. Describe the different kinds of cast iron.

14. What is wrought iron? How made?

15. Describe and sketch the Bessemer converter.

16. Describe briefly its operation.

17. Describe and sketch the essential features of an open-hearth furnace.

18. Describe briefly its operation.

19. Compare Bessemer and open-hearth steels.

METALLURGY

20. (a) What are the defects in ingots? How are these remedied? (b) State the different mechanical treatments applied to steel. (c) Describe each briefly.

21. Discuss the effect of heat treatment on steel.

22. Tabulate the approximate chemical composition of the various forms of iron and steel.

23. (a) What are the methods of reducing copper ores? (b) Describe each briefly.

24. How and why is copper refined?

25. Discuss briefly the smelting of lead.

26. Describe the methods of refining lead.

27. (a) What are the properties of zinc? (b) How is zinc ore wasted? (c) Describe briefly the zinc distillation process.

28. Outline briefly the metallurgy of gold.

29. What is the Hall process of aluminum reduction?

30. List and describe briefly the alloying elements. What are their influences?

REVIEW QUESTIONS

ON THE SUBJECT OF

WELDING

1. What does *welding* mean, as customarily applied?

2. Upon what factors does successful welding depend?

3. How may welding processes be classified?

4. What does *autogenous welding* mean?

5. Describe the different kinds of welds made by smith welding, and their applications.

6. Why, in electric-arc welding, is the metal to be welded connected to the positive side of the electric supply circuit?

7. Describe the Benardos system of electric-arc welding.

8. Discuss the cost of arc welding.

9. An iron beam of 25 square inches cross-section is to be cut by the electric-arc method. The current to be applied is 500 amperes. In what time can this beam be cut?

10. Describe the process of electric riveting.

11. Discuss the characteristics of butt and spot welding.

12. It is desired to weld, by the butt-welder method, two iron rods 1 inch in diameter. State the horsepower required at the dynamo, the time required to make the weld, and the cost for 100 welds at a price of 3 cents per kilowatt hour.

13. What are the advantages of gas welding? What are the limitations?

14. What is blau gas?

15. Describe the different methods of commercial production of oxygen.

16. What are the general features of the oxy-acetylene welding process?

17. Which type of acetylene generator is most used?

18. Discuss the cost of oxy-acetylene welding.

19. What are the advantages of blau-gas welding?

20. Describe the cutting of metals by means of gases.

21. It is desired to cut by the hot-flame method 30 feet of iron plate ½ inch thick. What would be the approximate cost of straight cutting?

22. Give a short description of the thermit-welding process.

23. What is the average tensile strength of a thermit weld?

24. Make wiring diagram for the C & C electric-arc welding system.

25. On what does the amount of electric current used in welding operations depend?

REVIEW QUESTIONS

ON THE SUBJECT OF

DIE MAKING AND METAL STAMPING

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1. What is essentially the first step in making any tool from a tool-maker's standpoint?

2. What rule is given for clearance?

3. Give one good method for making the punch and die.

4. What is a stripper?

5. In making irregular shaped dies what precaution must a die-maker take?

6. Describe the process in preparing a die block?

7. Give a method of laying out a die. What tool is used in connection with such work?

8. How are dies shaped?

9. If the degree of clearance is small, why must attention be given to the walls of the die?

10. What can you say in regard to filing corners of a die?

11. What effect has the hardening of a die in a bath of mercury?

12. What material is used in connection with hardening to protect corners of a die?

13. Describe the tempering process.

14. How does laying out of a punch differ from that of a die?

15. What is a sub-press die?

16. Describe the method of making a press body.

17. What is a master plate and when is it used?

18. When are dies made in sections?

19. What precaution must be taken in making a built-up die?

20. What is the object in tapping dowel holes?

21. How are die pieces placed in a shoe?

22. What can you say in regard to grinding of punch sections of a blanking die?

23. What difference is to be observed between gang dies and the simpler dies?

24. Describe the method of holding punches and blanking dies.

25. Why are piercing punches inserted first in the piercing holes?

26. What is the two-punch principle?

27. What is the advantage of the two-punch method?

28. What precautions must be taken in making a lower punch?

29. How is the upper punch made?

30. What is a drawing die?

31. What care must be exercised in making a drawing punch?

32. What is stock wrinkling?

33. Describe the irregular drawing die.

34. What is meant by the term "crawl"?

35. Name the methods of making embossing dies.

36. Name some articles which may be made with fluid dies.

37. What is the use of a rubber core?

38. Describe drop-forging dies.

39. How is a dovetailed shank formed?

40. What is meant by squaring?

41. How are dies recessed?

42. What allowance is made for shrinkage?

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